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Can private domestic investment lead Chinese technological progress?☆

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A B S T R A C T

This study examines the effects of private domestic investment (PDI), foreign domestic investment (FDI), state-owned units' investment (SOI) and their interactions on technological progress in China. Specifically, we test whether PDI leads Chinese technological progress, and crowd-out effects from FDI and SOI. The empirical analysis is based on panel data consisting of 29 Chinese provinces and municipalities over 1989–2014. We extract technological progress using the panel stochastic frontier model and examine its determinants. Our findings suggest that while PDI, FDI and SOI all positively contribute to technological progress in China, PDI is the dominant contributor.

1. Introduction

In this paper we examine the effects of different forms of investment, namely state-owned units' investment (SOI), private domestic investment (PDI) and foreign domestic investment (FDI), and their interactions on technological progress in China. This research is important for the following reasons. First, economic theories perceive an important role for investments in promoting technological progress. Johansen (1959), for instance, states that the effect of technological progress hinges on the rate of investment, asserting that no technological change can be achieved without investment. Similarly, studies by Arrow (1962), De Long and Summer (1991) and Boucekkine et al. (1998) hypothesize that continuous investment in the purchase and use of new machines and equipment induce technical change through the process of learning-by-doing. These studies argue that the rate of acquisition and adaptation of new equipment and machines are manifested in investments by firms. Further, investment in infrastructure and fundamental industries by states induces the adaptation of better technologies by firms (Aschauer, 1989; Everaert and Heylen, 2001; Montolio and Sole-Olle, 2008; Vijverberg et al., 2011; Bottasso et al., 2013).

Second, enhanced technology shifts production curve upwards and is beneficial to long-term economic growth (Park, 1995; Ezaki and Sun, 1999). Third, majority of the existing empirical literature fails to differentiate among different forms of investment when investigating the relationship between investment and technological progress. For instance, Aitken and Harrison (1999) examine technological impacts of FDI in Venezuela; Bottasso et al. (2013) study technological impacts of public investment in OECD countries; many studies on China, such as Lin et al. (2011) and Yi et al. (2013), investigate the impact of FDI on Chinese technological progress; and Han and Shen (2015) examine technological impacts of both FDI and domestic investment in China.

Fourth, there is lack of conclusive empirical evidence on specific forms of investments and their impacts on technology. For instance, technology's impact of FDI in China is found to be positive in Lin et al. (2011) but negative in Yi et al. (2013) and Han and Shen (2015). Fifth, another group of studies, including Young (1993), Aitken and Harrison (1999) and Liu (2008), postulate that investments' impacts on technology can potentially be influenced by the interactions of different forms of investments. Young (1993) argues that complementarity or crowding-in effect between FDI and domestic investment will potentially enhance technology given that FDI inflows are, to a large extent, determined by domestic factor endowment. Complementarity is also evidenced in Narayan (2004) who studies public investment and private investment for Fiji over 1950–1975. In contrast, Aitken and Harrison (1999) and Liu

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Table 1
Estimation of stochastic frontier models.

Explanatory variable	Time-varying decay inefficiency model		Time-invariant inefficiency model	
	Coef.	s.e.	Coef.	s.e.
ln*K*	0.863***	0.193	0.678***	0.182
ln*L*	1.627***	0.373	1.123**	0.492
T	−0.023	0.024	−0.0004	0.023
$(\ln K)^2$	0.004	0.017	0.007	0.018
$(\ln L)^2$	−0.058**	0.026	−0.025	0.033
T^2	0.001***	0.000	0.001**	0.000
ln*K*ln*L*	−0.035	0.029	−0.023	0.032
*T*ln*K*	−0.005	0.004	−0.002	0.004
*T*ln*L*	0.009***	0.003	0.003	0.004
Constant	−6.387***	1.585	−3.855**	1.997
μ	0.557	0.092	0.543	0.086
σ_u^2	0.068	0.023	0.049	0.016
σ_v^2	0.008	0.000	0.008	0.000
γ	0.897	0.032	0.860	0.040

Notes: the table shows the time-varying decay inefficiency and time-invariant inefficiency estimates for Chinese provinces for the period 1988–2014; the coefficients and standard errors are given under the columns 'Coef' and 's.e', respectively; ***(**)* represent significance at the 10%(5%)1% levels; μ is mean of technical inefficiency, σ_u^2 is variance of technical inefficiency, σ_v^2 is variance of random error, and $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$.

(2008) propose that, due to substitution or crowding-out effect, unfair competition by foreign firms may increase average production cost of domestic firms and hence lower technological adaptation by domestic firms.

Based on these considerations, we propose three hypotheses. First, SOI, PDI, and FDI are likely to have positive effects on technological progress in China due to technical changes involved in investment. Second, PDI is likely to lead Chinese technology progress, given its growing importance in the Chinese economy. Third, technology effects of pairwise interactions among SOI, PDI, and FDI (in short, 'interactive technology effects' or 'interactive effects') are likely to be negative; that is, the three forms of investment play substitutional roles on promoting Chinese technological progress due to competition and factor endowment.

To test our hypotheses, we proceed in two steps. First, we use a rich data set on 29 Chinese provinces for the period 1988–2014 to calculate technological progress indices. Second, we run regressions on the indices to identify contributions of different forms of investments to technological progress in China.

Our approaches lead to three new findings. Our first finding is that SOI, PDI, and FDI all positively contribute to technological progress in China. Our second finding is that PDI has the largest effect on technological progress. From the negative signs of pairwise multiplications of SOI, PDI, and FDI, we find that the three forms of investment in general have substitutional effects on Chinese technological progress, which represents our third most important findings.

These findings provide a clearer understanding of the impacts investments have on technological progress, particularly from a developing country perspective. Each of these findings contributes to two specific literature. The first literature includes, amongst others, Aitken and Harrison (1999), Lin et al. (2011), Yi et al. (2013) and Han and Shen (2015). These studies investigate the technology-investment nexus in China and draw inconclusive evidence about investment's impact on technological progress. Our findings complement the empirical literature by showing that each form of investment has a consistent and positive impact on technological progress. The reason we obtain this result is because we simultaneously consider the possibility of investment's linear effect being affected by the presence of investments of the other forms.

The second literature we contribute to is Young (1993), Aitken and Harrison (1999) and Liu (2008). These studies demonstrate the ambiguity of the technology effect of interaction between domestic investment and FDI. Our findings of negative interactive effects contribute to the literature by supporting the substitution hypothesis with quantitative evidence in the case study of China.

Finally, we test the robustness of our findings along the following lines. First, we estimate technological progress indices by using two different models. Second, we differentiate the impacts of investments of different forms by time period and by zone due to different phases of the provincial economic reforms in China. Third, we calculate two series of capital stock and apply them in subsequent analyses. The key message of these robustness tests is that our main conclusion that PDI has the capacity to lead Chinese technological progress holds.

The rest of the paper is planned as follows. Section 2 describes methodologies and model. Section 3 presents data. Section 4 discusses the empirical findings, and Section 5 draws conclusions.

2. Models and methodologies

2.1. Estimation of technology: the parametric stochastic frontier analysis

In our empirical analysis, we employ the parametric stochastic frontier analysis to estimate technology level. This method follows a well-established tradition set by pioneering studies, such as Nishimizu and Page (1982), Battese and Coelli (1988) and Coelli et al. (2005). The general form of a stochastic production frontier is written as

$$Y = \exp(f(K, L, T))\exp(-u)\exp(v), u \geq 0, \tag{1}$$

where

<i>$Y =$</i> GDP at constant 2010 prices;
<i>K</i> = capital stock at constant 2010 prices. The perpetual inventory method is used to estimate capital stock using data on gross fixed capital formation over 1978–2014 period. Following Kruger (2003), capital stock in the initial year is approximated by $K_0 = I_0 \cdot (1 + g_I)/(g_I + \delta)$, where I_0 is investment in the initial year, g_I is average growth of investment over the subsequent five years and δ is national depreciation rate. Following Zhang et al. (2004), we set $\delta = 0.096$. The subsequent years' capital stocks are calculated as $K_t = (1 - \delta) \cdot K_{t-1} + I_t$;
L = education augmented labor input, $L = e^{EDU}POP$, where EDU is student enrolment in tertiary education institutions as a percentage of total population, and POP is total population in persons; and
T = a time variable.

The notation *f*(.) in Equation (1) denotes the production frontier assuming potential production level with full efficiency. The first error component u follows half-normal distribution, i.e., iid $N^+(0, \sigma_u^2)$. The notation $\exp(u)$ measures the distance between the actual productivity level and the frontier, hence captures production inefficiency. The second error component v is normally distributed, i.e., iid $N(0, \sigma_v^2)$. The notation e^v captures random shocks, and subscripts i and t, respectively, denote province and time.

The logarithmic form of a fixed-effect panel translog stochastic production frontier is defined as:

$$\ln Y_{it} = \beta_{0i} + \beta_1 \ln K_{it} + \beta_2 \ln K_{it} + \beta_3 t_t + \frac{1}{2}\left[\beta_4 (\ln K_{it})^2 + \beta_5 (\ln L_{it})^2 + \beta_6 t_t^2\right] + \beta_7 \ln K_{it} \ln L_{it} + \beta_8 t_t \ln K_{it} + \beta_9 t_t \ln L_{it} + v_{it} - u_{it} \tag{2}$$

Technological progress index, TP, is computed as the geometric mean between two consecutive years of partial derivatives of the production function with respect to time:

$$TP_{it} = \exp\left[\frac{1}{2}\left(\frac{\partial \ln Y_{i,t-1}}{\partial (t-1)} + \frac{\partial \ln Y_{it}}{\partial t}\right)\right] \cdot 100. \tag{3}$$

An index greater than 100 indicates positive technological progress and when it is less than 100, it indicates a decline in technology.

Table 2
Summary statistics of key variables (average over 1989–2014).

Province/Zone	GDP (2010 prices, billion yuan)	Capital stock (2010 prices, billion yuan)	Technological progress index TP_{tvd}	Technological progress index TP_{ti}	FDI per capita (2010 prices, yuan)	SOI per capita (2010 prices, yuan)	PDI per capita (2010 prices, yuan)	Number of state-owned firms and firms above designated size (unit)	Students enrolled in higher education institutes (1000 persons)
Beijing	685.6	1552.7	102.64	103.96	1590	5061	10,232	6729	373
Tianjin	443.3	1176.4	102.60	103.92	3058	6881	11,819	7230	228
Liaoning	952.9	2270.8	103.53	103.28	1305	3510	6461	17,837	483
Shanghai	892.9	2038.1	102.62	103.99	2752	6278	9367	12,241	313
Jiangsu	2035.7	4413.5	103.74	103.14	1360	2668	7820	38,336	821
Zhejiang	1367.2	2873.4	103.57	103.29	796	2980	7406	36,653	438
Fujian	750.3	1562.5	103.61	103.01	959	3014	5486	13,652	304
Shandong	1953.7	4389.1	103.94	102.93	509	1820	7500	27,253	778
Guangdong	2247	3726.4	103.95	102.99	1220	2080	4841	33,472	678
Eastern Zone	**1258.7**	**2667**	**103.36**	**103.39**	**1505**	**3810**	**7881**	**21,489**	**491**
Hebei	1045.3	2407.7	103.97	102.86	222	1886	5065	14,257	538
Shanxi	453.9	1137.6	103.65	103.22	130	3108	3819	6472	286
Inner Mongolia	507.7	1420.1	103.43	103.15	350	5489	8488	5007	171
Jilin	435.8	1238.7	103.51	103.20	188	2919	7309	7002	294
Heilongjiang	583.8	1267.4	103.67	103.19	289	2932	3544	8197	368
Anhui	647.9	1329.6	104.15	102.68	253	1913	2508	13,562	437
Jiangxi	476.3	996.9	103.98	102.79	356	1875	2522	9383	397
Henan	1153	2849.2	104.25	102.55	212	1371	5394	16,670	654
Hubei	832.5	1815.6	103.94	102.86	280	2429	4049	13,935	672
Hunan	823.9	1635.9	104.15	102.61	270	2040	3311	14,268	517
Hainan	109.8	278.9	102.98	103.40	894	2577	3621	805	64
Central Zone	**642.7**	**1488.9**	**103.79**	**102.96**	**313**	**2594**	**4512**	**9960**	**400**
Guangxi	485.5	1191.8	104.05	102.63	113	1740	4052	6840	266
Sichuan	1317.5	2956.2	104.30	102.58	259	2538	2761	22,950	807
Guizhou	251.6	606.1	104.05	102.65	27	2019	1645	3882	161
Yunnan	414.6	1081.7	103.93	102.81	87	2343	2923	4286	211
Shaanxi	491.5	1281.2	103.73	103.02	188	3918	3691	6609	478
Gansu	224.8	520.3	103.74	103.13	22	2827	1298	3722	184
Qinghai	71.2	249.6	102.68	104.09	191	4727	5391	821	24
Ningxia	80.6	277.3	102.74	103.86	66	3599	6426	1057	40
Xinjiang	296.7	884.2	103.21	103.63	42	4208	4636	3132	134
Western Zone	**403.8**	**1005.4**	**103.60**	**103.16**	**111**	**3102**	**3647**	**5922**	**256**
National Average	**759.7**	**1704.4**	**103.60**	**103.15**	**620**	**3129**	**5289**	**12,285**	**383**

Notes: the table displays the annual average statistics for dependent and explanatory variables used in the analysis over the period 1989–2014; zone average values and national average values are presented in boldface; the statistics are calculated based on data obtained from *China Statistical Yearbook* of various years and provincial statistical yearbooks.

Equation (2) is estimated with both time-varying decay inefficiency and time-invariant inefficiency models. Regression results are reported in Table 1. Technological progress indices, $TP_{tvd,it}$ and $TP_{ti,it}$, obtained from the two models are highly correlated; the coefficient of correlation is 0.8858.

2.2. Modelling technological progress

We propose the following econometric model to answer our research question:

$$TP_{it} = \sum \alpha X_{it} + \sum \varphi W_{it} + e_{it}, \tag{4}$$

where the vector of variables X_{it} is variables of interest including:

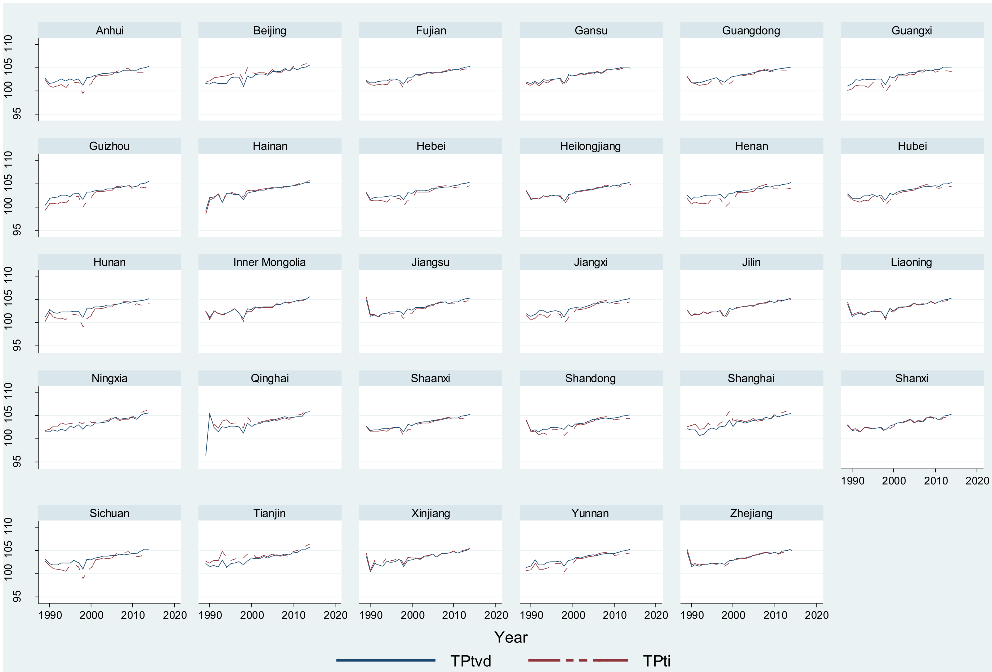
FDI_{it} = Natural logarithmic FDI per capita (2010 constant prices);
SOI_{it} = Natural logarithmic SOI per capita (2010 constant prices);
PDI_{it} = Natural logarithmic PDI per capita (2010 constant prices);
$FDI_{it} \times PDI_{it}$ = interaction between FDI_{it} and PDI_{it};
$SOI_{it} \times PDI_{it}$ = interaction between SOI_{it} and PDI_{it}; and
$SOI_{it} \times PDI_{it}$ = interaction between SOI_{it} and FDI_{it}.

The vector of variables W_{it} is control variables including:

$SPILLOVER_{it}$ = cross-provincial technology spillovers, which is calculated as $\sum_{j\neq i} TP_{jt} / \sum_{j\neq i} j$; and
$FIRMS_{it}$ = number of firms over designated size (natural logarithmic), used to capture competition among firms with innovation capacity.

We assume that: (a) investment incorporates new technologies; (b) a province with lower technological progress benefits from technology spillovers across provinces; and (c) a province with more firms over designated size has a higher innovative capacity compared to another province. Hence, we expect that *FDI*, *SOI*, *PDI*, *SPILLOVER* and *FIRMS* will have positive signs, consistent with studies such as Aschauer (1989), Everaert and Heylen (2001), Montolio and Sole-Olle (2008), Vijverberg et al. (2011) and Bottasso et al. (2013). The variable *FIRM* is likely to be positively associated with technology due to economies of scale (Lin et al., 2011). Similarly, a positive association between *SPILLOVER* and technology is expected due to the linkage effect (Lin et al., 2011).[1] Negative signs of the interaction variables ($FDI \times PDI$, $SOI \times PDI$ and $SOI \times FDI$) are expected due to the substitution hypothesis that one form of investment's impact on technology is reduced by an increase in another form of investment (Aitken and Harrison, 1999; Liu, 2008).

[1] The linkage effect takes place in circumstances where suppliers and sub-contractors in less developed provinces have production contracts with industries in more developed provinces and learn advanced technologies from them.



Notes: the figure shows estimated technological progress indices for Chinese provinces over the period 1989-2014; the blue curve represents technical progress index calculated from the time-varying decay inefficiency model, TP_{tvd}, and the red curve represents technical progress index calculated from the time-invariant inefficiency model TP_{ti}; estimation is based on data from *China Statistical Yearbook* of various years and provincial statistical yearbooks.

Fig. 1. Estimated technological progress indices, TP_{tvd} and TP_{ti} (1989–2014). Notes: the figure shows estimated technological progress indices for Chinese provinces over the period 1989–2014; the blue curve represents technical progress index calculated from the time-varying decay inefficiency model, TP_{tvd}, and the red curve represents technical progress index calculated from the time-invariant inefficiency model TP_{ti}; estimation is based on data from *China Statistical Yearbook* of various years and provincial statistical yearbooks. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Data

Mainland China has 33 administrative divisions, including 22 provinces, 5 autonomous regions, 4 municipalities, and two special administrative regions. The Tibet Autonomous Region is not covered in the current study due to unavailability of data over the sample period of the study. Moreover, Chongqing became a municipality only in 1997. Before 1997, its statistical data were part of the Sichuan Province statistics, hence it is covered in the current study as part of Sichuan Province. Two special administrative regions, namely Hong Kong and Macau, were reunited with Mainland China in 1997 and 1999, respectively. They differ from the rest of Mainland China in terms of their political and economic systems. Given these, the sample employed in this study covers Mainland China's 22 provinces, 4 autonomous regions and 3 municipalities: in short, our sample includes China's 29 provinces.

The sample period used in the translog production function covers 1988–2014. Constrained by provincial data on *FDI* and *SOI*, the sample period used in the technology model covers 1989–2014. Two sources of data are employed, namely, the *China Statistical Yearbook* of various years, and the provincial statistical yearbooks. Statistics on key macroeconomic variables, along with the estimated technological progress indices from the time-varying decay inefficiency model $TP_{tvd,it}$ and from the time invariant inefficiency model $TP_{ti,it}$, are summarized in Table 2. Estimated indices by province are also plotted in Fig. 1.

Technological progress in general increases over time with fluctuations (Fig. 1). Spatially, there are minute differences across zones in the estimated technological progress indices. Series including real GDP, capital stock, *FDI* per capita, *PDI* per capita, number of state-owned firms and firms above designated size, and students enrolled in higher education institutes, are highest in the Eastern zone, and lowest in the least developed Western zone. Moreover, *SOI* per capita is seen highest in the Eastern zone and lowest in the Central zone (Table 2).

The correlation matrix is presented in Table 3. We observe that correlation coefficients between non-interactive independent variables are all below 0.7, indicating that there is unlikely to be multicollinearity problems in using these independent variables simultaneously. Due to the nature of interactive terms, some of the correlation coefficients are above 0.7, which does not compromise the statistical relevance of the empirical model.

Table 3
Correlation matrix.

	$TP_{tvd,}$	SPILLOVER	FIRMS	SOI	PDI	FDI	SOI × PDI	FDI × PDI	SOI × FDI
$TP_{tvd,}$	1								
SPILLOVER	0.9400	1							
FIRMS	0.0083	−0.1301	1						
SOI	0.6800	0.6120	−0.2223	1					
PDI	0.7531	0.6432	−0.0278	0.6165	1				
FDI	0.3908	0.4775	0.1829	0.6092	0.6482	1			
SOI × PDI	0.7577	0.6659	−0.1044	0.7953	0.8211	0.6470	1		
FDI × PDI	0.5582	0.6699	0.1590	0.6327	0.7181	0.8004	0.7097	1	
SOI × FDI	0.5008	0.6175	0.1091	0.6563	0.6434	0.8220	0.6730	0.8288	1

Note: the table shows the correlation matrix between key variables.

Table 4
Results from Harris-Tzavalis's panel unit root test.

Variable	Trend	Panel means	Cross-sectional means	Rho statistic	p-value
TP_{tvd}	No	No	Yes	1.0012	0.5448
ΔTP_{tvd}	No	No	No	−0.3697	0.0000
TP_{ti}	No	No	Yes	0.8671	0.2891
ΔTP_{ti}	No	No	No	−0.2063	0.0000
SPILLOVER	No	No	Yes	1.0010	0.5386
ΔSPILLOVER	No	No	No	0.0248	0.0000
FIRMS	No	No	Yes	0.9979	0.4201
ΔFIRMS	No	No	No	0.0767	0.0000
SOI	No	No	Yes	1.0132	0.9002
ΔSOI	No	No	No	−0.2675	0.0000
PDI	No	No	Yes	1.0185	0.9574
ΔPDI	No	No	No	−0.2776	0.0000
FDI	No	No	Yes	1.0184	0.9501
ΔFDI	No	No	No	0.1946	0.0000

Note: Δ means first difference.

Table 5
Results from Pedroni's panel cointegration tests.

Tests	Test statistic	Test statistic
Panel *v*	62.51*	−3.865*
Panel *rho*	5.509*	3.64*
Panel *t*	4.283*	1.253
Panel *ADF*	3.604*	5.287*
Group *rho*	5.734*	4.362*
Group *t*	2.637*	0.4637
Group *ADF*	5.177*	4.61*

Notes: tests presented in the first column include time dummies, and tests presented in the second column exclude time dummies; * denotes significance at the 5% level.

4. Empirical findings

Given development differences among the Eastern Zone, Central Zone and Western Zone, regressions by zone are estimated. Further, given substantial improvement in marketization level,[2] along with other changes in the Chinese economy after the privatization programme and China's admission to the World Trade Organisation, the entire sample period is divided into two sub-periods, namely 1989–2000 and 2001–2014. This section summarizes and interprets empirical findings.

This section starts with panel unit root tests and a cointegration analysis, followed by a test of cross-sectional independence. The section concludes with a cross-sectional time-series feasible generalized least squares (FGLS) estimation of the main regression model (Equation (4)).

4.1. Panel unit root tests and cointegration analysis

All variables used in Equation (4) are tested for panel unit roots. The Harris-Tzavalis unit-root test is employed with the null hypothesis that panels contain unit roots (see Harris and Tzavalis, 1999). According to test statistics summarized in Table 4, all variables involved in assessing the determinants of technology are integrated of order one.

Pedroni's (1999) panel cointegration tests are used to find out whether the combination of variables in Table 4 yields stationary error terms. Two sets of tests are conducted, one with and one without time-specific effects, to test the null hypothesis of no cointegration. All test statistics follow a standard normal distribution. According to test results in Table 5, all seven tests reject the null hypothesis at the 5 percent significance level when a time trend is included in the tests, while five tests reject the null when the time-specific effect is not considered. These results provide evidence of cointegration amongst variables depicted in Equation (4).

4.2. Test of cross-sectional independence

Pesaran et al. (2008) test is employed to test for the null hypothesis that cross-sectional error terms are independent. Pesaran, Ullah and Yamagata test statistics are obtained from estimating Equation (4) with the fixed effects estimator. Results, reported in the bottom row of Table 6, consistently reject the null hypothesis. We conclude that there is cross-sectional dependence. Hence, to control for cross-sectional dependence, the FGLS estimator is employed in explaining technological progress.

4.3. Regression results and interpretation

With no evidence of the endogeneity problem, Equation (4) is estimated with the FGLS estimator controlling for heteroskedasticity, cross-sectional dependence and panel-specific autocorrelation of order one. Regressions are run on two technological progress indices, one obtained from a time-varying decay inefficiency model and the other from a time-invariant inefficiency model. Since regression results from these two models are consistent in terms of signs on slope coefficients, our interpretation of the findings focuses on the results from the former model.

Empirical findings are summarized as follows:

1). Technology spillovers across provinces (*SPILLOVER*)

Cross-provincial technology spillovers have positive and highly significant coefficients in all regressions. This indicates that technologies create spillover effects among Chinese provinces and enhances recipient provinces' technological progress. A one percentage point increase in spillovers on average leads to a 0.911 percentage point increase in technological progress in China (Column 1 in Table 6). On the other hand, a one percentage point increase in spillovers increases technological progress in the Eastern, Central and Western zones by 0.785, 1.091, and 1.064 percentage points, respectively (Columns 4 to 6). Overall, the impact of spillovers increased impressively in the new millennium (Columns 2 and 3).

2). Number of firms above designated size (*FIRMS*)

There is strong evidence that number of firms above designated size has positive impact on technology in the Eastern zone. This effect increased in the 2001–2014 period compared to the 1989–2000 period. This confirms that in the well-developed Eastern zone, economies of scale allows large firms to build their competitive ability and accumulate sufficient resources in the long term to adopt new technologies. Impacts of *FIRMS* on technology in the Central and Western zones are found insignificant.

3). Investments of three forms (*SOI*, *PDI* and *FDI*)

In general, all three forms of investments have positive impacts on provincial technological progress. With respect to statistical evidence, *SOI*'s impact is highly significant in all three zones (Columns 4 to 6). The *FDI*'s influence is most significant in the Eastern zone and least significant in the Central zone. The *PDI*'s contribution, by comparison, is highly significant in the Eastern and Central zones. With respect to impact (magnitude-wise), the *PDI*'s influence is the largest among the three forms of investment (Columns 1 to 3). These results confirm that *PDI* has the capacity to lead technological progress in China.

Further, a significant increase in the magnitude of all investment was noted in the 2001–2014 period compared to the 1989–2000 period. This confirms the increasingly strong role of different forms of investment in China.

[2] Marketization in China involves the integration of competition and price mechanism into the public and private sectors. The marketization reform is a major component of China's economic reforms.

Table 6
Regressions of technological progress indices.

	Dependent variable: TP_{tvd}						Dependent variable: TP_{ti}					
Coverage	National	National	National	Eastern	Central	Western	National	National	National	Eastern	Central	Western
Period	1989–2014	1989–2000	2001–2014	1989–2014	1989–2014	1989–2014	1989–2014	1989–2000	2001–2014	1989–2014	1989–2014	1989–2014
Explanatory variable	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
	z stat	z stat	z stat	z stat	z stat	z stat	z stat	z stat	z stat	z stat	z stat	z stat
SPILLOVER	0.911***	1.099***	1.313***	0.785***	1.070***	1.064***	0.985***	1.088***	1.266***	1.004***	1.087***	1.004***
	440.28	27.44	106.87	61.72	236.16	433.02	433.41	44.73	76.34	105.80	242.83	194.02
FIRMS	1.252***	1.743**	10.167***	0.363**	−0.027	0.086	0.624***	0.701***	3.574***	0.077	0.040	0.003
	23.23	7.74	54.31	2.13	−0.38	1.47	36.49	6.25	56.01	1.57	1.13	0.08
SOI	3.655***	4.687**	12.690***	3.623***	3.701***	0.678***	1.549***	2.761***	2.171***	1.037***	0.996***	0.055
	15.41	2.15	4.76	3.84	9.14	2.54	22.34	4.10	2.54	3.03	5.64	0.32
PDI	3.785***	5.297***	29.544***	3.263***	3.373***	0.525*	1.565***	2.952***	4.929***	1.032***	0.836***	0.020
	16.36	2.59	10.85	4.18	8.31	1.86	22.80	5.36	5.15	3.31	4.94	0.13
FDI	2.050***	2.263**	15.936***	2.307***	0.509**	0.307**	0.746***	0.755**	2.997***	0.591**	0.266***	0.236***
	13.45	2.34	8.07	3.31	2.40	2.56	19.70	2.08	6.04	2.02	2.62	2.75
SOI*PDI	−0.409***	−0.852***	−2.675***	−0.315***	−0.440***	−0.052	−0.188***	−0.436***	−0.531***	−0.103***	−0.119***	−0.002
	−14.37	−2.85	−7.79	−3.20	−8.05	−1.45	−21.49	−4.80	−4.87	−2.62	−5.37	−0.11
FDI × PDI	−0.159***	−0.017	−2.673***	−0.130***	0.005	−0.009	−0.049***	0.010	−0.502***	−0.041**	0.002	−0.012
	−15.39	−0.19	−14.11	−2.62	0.87	−0.59	−15.85	0.22	−10.57	−2.10	0.57	−1.30
SOI × FDI	−0.189***	−0.316***	0.219	−0.204**	−0.070**	−0.037*	−0.082***	−0.126***	−0.009	−0.053	−0.042***	−0.028**
	−10.51	−3.13	0.89	−2.20	−2.23	−1.72	−18.21	−4.09	−0.12	−1.34	−2.80	−2.01
New Millennium	−0.33***			0.18	0.03	−0.10	−0.068**			−0.003	−0.081	−0.003
	−4.86			0.84	0.12	−0.91	−2.28			−0.05	−0.73	−0.04
Constant	−32.494***	−56.464***	−280.129***	−14.154*	−31.550	−12.690***	−16.110***	−34.642***	−80.938***	−10.118***	−15.896***	−0.939
	−14.67	−4.06	−16.01	−1.82	−9.80	−6.00	−22.94	−7.97	−11.28	−3.58	−11.16	−0.74
Pesaran et al. stat (p-value)	23.25	6.28	26.92	2.26	8.77	4.19	19.65	3.71	24.49	1.91	8.02	5.61
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.05)	(0.00)	(0.00)

Notes: Pesaran et al. statistics are obtained based on the fixed effects estimator; the FGLS estimator is used in the regressions, where heteroskedasticity, panel-specific AR(1) and cross-sectional dependence are specified; ***(**)* represent significance at the 10%(5%)1% levels; *New Millennium* is a binary variable with value zero for years 1989–2000 and unity for years 2001–2014.

Table 7
Robustness analysis, regressions of technological progress indices.

	Dependent variable: TP'_{tvd}				Dependent variable: TP'_{ti}			
Coverage	National	Eastern	Central	Western	National	Eastern	Central	Western
Explanatory variable	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
	z stat	z stat	z stat	z stat	z stat	z stat	z stat	z stat
SPILLOVER	0.766***	0.274	0.136***	2.568***	0.993***	1.000***	1.024***	1.002***
	8.88	1.56	2.15	13.37	236.19	305.17	97.23	167.47
FIRMS	0.125***	2.893***	−0.014	0.617***	0.162***	0.031**	0.003	0.005
	3.35	12.17	−0.26	4.11	21.27	1.96	0.32	0.36
SOI	5.764***	10.105***	6.095***	1.447***	0.476***	0.391***	0.365***	0.056
	21.30	5.53	17.89	3.42	17.79	3.64	8.27	0.87
PDI	6.098***	14.063***	6.673***	1.089***	0.443***	0.406***	0.291***	0.074
	21.69	9.01	16.76	15.39	16.74	4.13	8.17	1.16
FDI	4.742***	7.241***	2.779***	0.850***	0.206***	0.226***	0.029	0.098***
	25.65	11.22	6.50	4.34	17.28	2.50	1.61	2.88
SOI × PDI	−0.657***	−0.747***	−1.044***	−2.017***	−0.056***	−0.039***	−0.045***	−0.010
	−19.54	−3.60	−19.76	−16.55	−16.29	−3.20	−8.24	−1.19
FDI × PDI	−0.305***	−1.558***	−0.212***	−0.360***	−0.010***	−0.017***	−0.006***	−0.005
	−26.01	−11.19	−6.15	−4.73	−8.80	−2.99	−3.51	−1.43
SOI × FDI	−0.424***	−0.967***	−0.252***	−0.057	−0.025***	−0.018	−0.010***	−0.011***
	−21.70	−5.26	−4.79	−0.62	−16.34	−1.49	−3.52	−2.21
New Millennium	−0.07	0.41	−1.22***	−3.34***	−0.032***	0.006	0.001	−0.003
	−0.55	0.73	−6.41	−6.12	−2.27	0.31	0.04	−0.10
Constant	−23.510***	−33.102***	−49.990***	−16.295***	−4.321***	−3.772***	−4.644***	−0.090
	−22.86	−10.29	23.41	23.05	−15.73	−4.15	−13.81	−0.18
Pesaran et al. stat (p-value)	10.32	2.84	12.35	0.66	17.77	1.69	7.52	4.42
	(0.00)	(0.00)	(0.00)	(0.10)	(0.00)	(0.09)	(0.00)	(0.00)

Notes: Pesaran et al. statistics are obtained based on the fixed effects estimators; the GLS estimators are used in the regressions, where heteroskedasticity, panel-specific AR(1) and cross-sectional dependence are specified; ***(**)* represent significance at the 10%(5%)1% levels; *New Millennium* is a binary variable with value zero for years 1989–2000 and unity for years 2001–2014.

4). Interaction between *PDI* and *SOI* (*SOI* × *PDI*)

The interactive effect of *SOI* and *PDI* (*SOI* × *PDI*) on technology is found to be negative, suggesting that *SOI* and *PDI* are substitutes in terms of promoting provincial technological progress. In other words, an increase in *SOI* is likely to reduce *PDI*'s impact on technological progress; similarly, an increase in *PDI* is also likely to reduce technology's impact of *SOI*. This type of effects is seen highest in the Eastern zone. Further, the negative magnitude of substitutional effect turns stronger quantitatively in the new millennium.

5). Interaction between *PDI* and *FDI* (*FDI* × *PDI*)

The negative coefficient of *FDI* × *PDI* in Column 4 suggests that *FDI* and *PDI* are substitutional in promoting technological progress in the Eastern zone. However, no statistical effect is found in the Central and Western zones (Columns 5 and 6). Furthermore, the substitutional effect is statistically insignificant before the new millennium, but becomes highly significant in the new millennium (Columns 2 and 3).

6). Interaction between *SOI* and *FDI* (*SOI* × *FDI*)

There is evidence that *SOI* and *FDI* are substituting each other's impact on technological progress, with the highest substitutional effect seen in the Eastern zone (Columns 4 to 6). Such interactive effect is found to be statistically significant in the initial period (1989–2000); however, the effect turns positive but becomes statistically insignificant in the later period (2001–2014) (see Columns 2 and 3). This, along with the fact that China significantly invested in infrastructure in the past few years,[3] may suggest that gradual privatization of state-owned enterprises and refocusing of state resources to infrastructure and other social capital formation mitigated the negative influence of state investment on *FDI*'s impact on technological progress noted in the earlier period.

The findings from the interactive effects seem to suggest that before the new millennium, *SOI* and *FDI* had minimum negative impacts on indigenous firms' ability to adopt new technologies. However, subsequent inflow of *FDI* and resulting competition for market share gradually diminished domestic firms' ability to adopt more advanced technologies. Similarly, massive fiscal stimulus hampered domestic firms' ability to secure appropriate finances to credit for better technologies (OECD, 2016). As a policy measure, the central and local governments should encourage *PDI* and *FDI* to engage more in research and development activities, and more public-private partnership should be encouraged in high-tech industries.

4.4. Robustness analysis

To test the robustness of the above empirical findings, we estimate capital stock by using a different depreciation rate and apply an alternative way to approximate initial year's capital stock. This new capital stock series is then applied in subsequent empirical analyses. In the literature, capital stock depreciation rate varies from 0.3 in Mankiw et al. (1992) to 0.10 in Kruger (2003), with Zhang et al. (2004) advocating a rate of 0.096, which is widely adopted in studies that use Chinese data. Similarly, the initial capital stock level is approximated in a few ways, including $I_0/(g_I+\delta)$ in Hall and Jones (1999), $I_0\cdot(1+g_I)/(g_I+\delta)$ in Kruger (2003), $I_0/0.1$ in Zhang et al. (2004), and $GDP_0 \times 2$ in Yao and Wei (2007). We calculate a series of capital stock, K', with $K'_0 = I_0/0.1$ and $\delta' = 0.3$. It is found that K and K' are highly correlated with a correlation coefficient of 0.9992.

Application of K' in the stochastic frontier analysis yields new series of technological progress indices, TP'_{tvd} and TP'_{ti}. Results of regressions on TP'_{tvd} and TP'_{ti} are in general consistent to TP_{tvd} and TP_{ti}'s regression results (see Table 7). This provides evidence that our results are robust.

5. Conclusion

This paper uses data on China's 29 provinces over the 1989–2014 period and investigates impacts of different forms of investments on

[3] In 2015 alone China invested 56 trillion yuan in infrastructure, approximately 13% of China's GDP (OECD, 2016).

technologies. It is found that the three forms of investments (PDI, FDI, and SOI) positively contribute to technological progress in China. Moreover, we find that PDI's contribution is most significant. It is also evident that PDI's contribution is reduced by the presence of FDI and SOI. These findings suggest that with the substantial achievements in economic development, competition resulted from subsequent inflows of FDI diminished domestic firms' ability of adopting more advanced technologies. Similarly, subsequent fiscal stimulus also erodes domestic firms' ability to secure appropriate finances to credit for better technology (OECD, 2016).

These findings indicate that both internal and external sources of technologies are important for improving technology in China. While governments should continue to attract FDI in high-tech industries particularly in less developed provinces, they should provide policy measures to encourage further innovation by PDI which has emerged as a more and more important contributor to technological progress. Government should also institute further financial reforms to provide better and cheaper finance to private domestic firms, empowering them with higher capacity to adopt advanced technologies. With the evidence that Chinese private domestic sector has been developing its R&D capacity, it is not hasty to claim that this sector would lead Chinese technology development in the future.

Lastly, it is found that all variables (*SPILLOVER*, *FIRMS*, *SOI*, *PDI*, and *FDI*) are likely to speed up technological progress in the least developed Western zone. Hence, besides building infrastructure and communication network to provide better connectivity to this zone, government should provide incentives, such as financial package, tax holidays, grants, and subsidies, to facilitate R&D activities by private firms. To mitigate negative impact of state investment on PDI, more state investment should be channelled to develop human capital (including provision of more scholarship and funding to schools and universities), and building the industrial base. Central and local governments should formulate effective policies to encourage advanced technologies, quality physical and human capital to spread from well-developed provinces to less developed provinces. This will also help reduce cross-provincial income gap.

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