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Does public R&D complement or crowd-out private R&D in pre and post economic crisis of 2008?

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ABSTRACT

Research and development expenditure (R&D) generate innovation and contribute significantly to the economic development. Previous studies emphasized the role of public R&D to encourage the technological innovation in the private sector. However, the effect of global economic crisis with respect to the public and private R&D link has been somewhat neglected in the empirical literature. Based on system GMM estimation, we found that public R&D complements private R&D in pre and post economic crisis. However, the strength of their complementary association is found strong in pre-economic crisis. In sum, the results indicate that continuous support to public R&D in pre and post economic crisis accelerate the technological innovation in the private sector. This study implies that public support to R&D is a good strategy for an economy to confront economic crisis effectively by increasing the technological innovation in the private sector. For policy makers, it is suggested that care must be taken while investing in the R&D, the investment is to be based on the ratio between R&D expenditure to number of R&D workers.

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R&D: innovation: economic crisis

1. Introduction

The 2008 financial crisis started in USA after the bankruptcy of Lehman Brothers with its effects felt across the world. Ireland, Spain, Greece, Portugal and many other European countries went into deep recession. Led by economic downturn, both the demand and supply sides of those economies shrunk with increasing trade imbalances and sovereign debt crisis. In response to the severe economic situations, European Commission Bank (ECB) lowered the interest rate and increased its refinancing for the banking system to protect the European financial markets. Not limited to American and European markets, those economic woes also badly affected the Asian economies. Countries such as China, Korea, Turkey and Japan suffered low output growth because of their economies were highly integrated to the European financial markets and they are sensitive to global trade downturn (see Blizkovsky, 2013; Holland, Barrell, & Fic, 2009).

Despite the economic crisis, many countries invested in technological innovation. There were two major reasons: First, technological innovations boost economic growth directly (see Hasan & Tucci, 2010; Bilbao-Osorio & Rodriguez-Pose, 2004) and second, they generate positive externalities in the form of knowledge creation. Accordingly, many

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economies used fiscal support such as tax cuts and subsidies and increased spending in innovation. For example, Germany increased public spending on R&D support programs. Chinese government used stimulus package worth of 172–586 USD billion between 2009 and 2010 to boost innovation. Countries like Sweden and Austria also increased their spending on innovation activities (Brautzsch, Gunther, & Loose, 2015; Filippetti & Archibugi, 2011; Gemmell, 2011). While technological advanced countries with high human capital and R&D backed by strong financial sector offset the economic crisis effectively (Filippetti & Archibugi, 2011) concluded that technological innovation did play a key role in the economic development.

Innovative products and services increase aggregate consumption, firms' profits and export sales of high technology products and services which reduce trade deficits. Particularly, R&D expenditure and human capital generate new knowledge, improve output per worker, and increase the economic efficiency (Pessoa, 2007). An economy with a new level of technology experience low average total cost (ATC) in the long run by operating on an efficient scale (low cost and high output), consequently, such technology decreases cost per unit and reduces the price level, shifting the market demand curve upward and increasing production and employment (Vivarelli, 2014).

Many endogenous growth models (e.g., Miguel-Angel and Maria-Teresa, 2013; Ahmed, 2012; Alfaro, Lopez, & Nevado, 2011; Fagerberg & Srholec, 2010; Metcalfe, 2010; Ulku, 2007; Wu, 2010) propose a positive link between technological innovation and economic growth. On the other hand, studies stressed the two major roles of R&D, first, R&D produce radical innovations and second it generates new knowledge in the form of increasing absorptive capacity (Cohen & Levinthal, 1990); and these two roles positively influence the economic growth (Akcali & Sismanoglu, 2015; Huffman, 2001). Previous studies (see Gemmell, 2011; Hausman & Wesley, 2014) also indicate that economies with strong R&D background and government support help in recovery from the economic crisis. Innovation led by R&D investment increases consumer spending, productivity, profitability and creates more jobs, reduces trade deficits, and increases revenues for the government (Hausman & Wesley, 2014). Our study proposes and develops an empirical approach measuring the effect of public R&D on private R&D in pre and post economic crisis of 2008.

Although with huge benefits, private R&D is costly and risky. Countries with short history of R&D may require more innovation support from government. Government R&D funding programs are specifically designed to correct the market failures, encourage innovation, and provide positive externalities to the rest of the economy (Czarnitzki & Fier, 2001). Governments fund the R&D in private sector mainly through subsidies on R&D projects (i.e., sharing the cost of R&D), grants, procurement and tax credits (Guellec & De La Potterie, 2003). Meanwhile, R&D can be financed by governments through expenditure on public universities and laboratories. With direct (subsidies) and indirect R&D (tax credits) support programs, private R&D can be stimulated to convert non-profitable projects into profitable ones. Such measures can also increase the wages of the scientists and help businesses to exploit new innovative opportunities, thus reduce the uncertainties associated with the private R&D.

Public R&D is used to accelerate technological innovation, increase national output and improve the standard of living (Coccia, 2010) while, private R&D is more directed to produce novel innovations and obtain monopoly power in the market. To date we have

a mixed outcome in the empirical literature regarding the public and private R&D link. In particular, this study re-investigated the relationship between public and private R&D by taking into the account of economic crisis of 2008 using macro-level panel data on 10 countries (mainly OCED).

In the past, several previous studies (Coccia, 2010; Guellec & De La Potterie, 2003; Koga, 2005; Levy & Terleckyj, 1983; Pop-Silaghi, Jude, Alexa, & Litan, 2014; Wu, 2005) identified the complementary association between public and private R&D, suggesting that public or government financed R&D (subsidies, tax credits or grants, university R&D) stimulate the R&D in the private sector. To the best of our knowledge, previous studies have been failed to neglect the effect of economic crisis in public and private R&D relationship. More precisely, this study examines the following two research questions. Does public R&D complement or crowd-out the private R&D in pre and post economic crisis (hypothesis 1)? Is the effect of public R&D on private R&D in pre and post crisis is robust across manufacturing and services sector and also across regions (hypothesis 2)?

The paper is structured as follows. Section 2 reviews the literature i.e., theoretical background. After presenting data and descriptive statistics in Section 3, we provide regression analysis in the section 4. Section 5 concludes with policy implications.

2. Theoretical background

To begin with earlier research related to innovation and growth, one of the fundamental models inducing innovation as an endogenous variable to explain growth is the Schumpeterian model. The defined "Schumpeterian paradigm" (Aghion & Howitt, 1992; Aghion et al., 1998) constructed modern industrial organization theory by emphasizing the importance of firms and entrepreneurs within the whole process of growth. As such, his model linked the micro-level economy (firm-based) and entrepreneurial skills (complementary variable to the firms' organizational structure) to the macro-level economy (growth). The paradigm is supported by three main theoretical proposals.

The first proposal is based on innovations that might be in support of productivity of production factors, product innovations and/or organizational innovations. All of these are subject to an amplified growth. The second proposal relies on investments done in support of research and development that push the innovation forward. These kinds of investments are helpful in the skills acquirements and their contribution to the firms themselves, to the gap's inspection of the markets and consumer preferences. The third proposal, as a consequence of the two above-mentioned proposals, is defined as the "creative destruction". While new technology, innovation and methods are induced, the old ones are considered out-of-date. This means that highly developed countries, the ones that are leading innovation to growth, have additional "replacement" or "adjustments" costs. These high costs are associated with relatively high firms and labor turnover rates in these countries.

Summing up these three proposals, the growth involves a conflict between the "old systems" and the "new ones". Said that, a balance should be maintained between pushing innovation and protecting as much as possible the labor market. Another important dimension related to the innovation is for sure the identification of the actors maintaining this balance. State is considered to be one of the main actors in innovation given the fact that the private firms tend to underinvest in R&D, training, etc. According to Aghion

and Akcigit (2015), underinvestment of private firms is reinforced by the existence of credit market imperfections which become particularly tight in recessions.

While considering the firms' profiles, Schumpeter's theory states that big firms are more innovative, or in other words, there are returns to scale in R&D among large firms (Schumpeter, 1942). This implies that the developed economies are more likely to have appropriate climate for innovation rather than the developing countries. Countries with a strong economy and well-established institutions can be a good environment for the innovation processes. From the other side, neo-Schumpeterian growth model states innovative entrepreneurship is the mechanism by which productivity growth is introduced in advanced economies. In these economies, innovation and structural change are more likely to take place through the combined efforts of entrepreneurial small ventures and large innovative firms (Baumol, 2002; Nooteboom, 1994). Contrary to that, the developing countries may face difficulties in engaging with the innovation. According to Alfaro, Yu, Rehman, Hysa and Kabeya (2019), the Schumpeterian environment hardly exists in developing countries because these countries generally have underdeveloped or a total lack of innovative infrastructure (including all the components of national and entrepreneurial framework conditions). Thus, innovation for them may come from abroad or from other users in the same country, or it may be created by public or private R&D labs or firms in the same country (Alfaro et al., 2019).

Strictly speaking, this study analyzed the Public-Private R&D link by taking into the account of economic fluctuations in pre and post crisis of 2008. Schumpeter (1936) was one of the earlier writers who wrote about the effect of innovative behavior of an entrepreneur during the business cycle. Schumpeter proposed that entrepreneurs are pro-cyclical. They introduce new technologies and transformed these existing technologies into successful innovations and generate economic equilibrium. Through this innovation process, the economy experience growth and boom. Later, when imitation starts in the economy, consequently the entrepreneurial profit is reduced until new entrepreneurs enter the market and introduce more "radical innovations" and create new economic equilibrium. On the other hand, Parker (2012) argued that entrepreneurs enter the market even in the economic downturn and they introduce innovations and seeds the future growth with productivity increase and high living standards. However, the risk-taking behavior of an entrepreneur during the time of crisis is somewhat dependent on the incentives to innovate.

Other researchers (e.g., Geroski & Walters, 1995; Rafferty, 2003) emphasized that business cycle create output volatility and result in low economic growth and innovation activity. In other words, innovation is pro-business cycle stated by Geroski and Walters (1995), the aggregate demand in the economy drives the innovation activity which stimulates technological innovation. For instance, the demand-pull factors such as sales, profits stimulate technological innovation through R&D investment. To support the previous argument, Rafferty (2003) stressed the importance of cash flows (real expenditures) to influence the R&D expenditure over the business cycle. His paper explored that in recession, the demand is low and that reduces the productivity (supply side of the economy) and thus reduce the innovation activity in the economy. Strictly speaking, R&D expenditure is pro-cyclical due to cash flow effect, in recession the cash flow negatively effects the R&D expenditure and result in low innovation activity. For instance, Wald and Woitek (2004) conducted a study on G7 countries using the R&D expenditure and economic growth data. They found that R&D expenditure is procyclical through correlation plot and rejected the argument of countercyclical effect of R&D. In sum, the primary focus of this study is to examine effect of public R&D on private R&D in pre and post economic crisis of 2008.

2.1. Micro level evidences

Empirical studies at micro level reports the two possible links between public and private R&D. Firstly, there exists a complementary relationship (positive) between public R&D (government funded) and private R&D. Secondly, the public R&D may crowd out (negative) private R&D, which is called substitution effect. Not all firms receive complementary benefits from public R&D, for example, the study of Guellec and De La Potterie (2003) suggests that public R&D expenditure in the form of subsidies, grants or tax credits goes to the large firms because of their strong R&D track record in the past due to their economic efficiency. In comparison, small- and medium-sized enterprises are usually financially constrained in terms of investment in the R&D due to its risk nature. Such biased strategy of public funded R&D favors large firms at the expense of SMEs which result in distortion in the market competition. Another reason could be that most of the R&D funding allocated to the payment of wages to the researchers and thus increases the input costs.

Ali-Yrkko and Jyrki (2004) conducted a panel study on Finnish firms. They explored the complementary link between public and private R&D. According to them, research grants, subsidies and tax credits (fiscal incentives) reduce the cost of private R&D. Koga (2005) also showed that public R&D (mainly subsidies) positively affects the private R&D using a panel study on 223 Japanese high-tech firms (electronics and motor vehicles). These subsidies from the government are mainly used for training and development of scientists and engineers at research institutions which stimulate the private R&D. Gonzales and Pazo (2008) and Gorg and Strobl (2007) used matching propensity score for Spanish and Irish manufacturing firms, and also examined that firms with R&D subsidies and grants accelerate the private R&D. They found the complementary association between public and private R&D.¹ In addition, Lach (2002) conducted a panel study on Israeli manufacturing firms and found public R&D stimulate private R&D for small firms. Time series analysis used by Petkovova, Cadil, Mirosnik, and Rehak (2015) on Czech Republic firms showed positive association between public R&D and private R&D and suggested that private sector generate more innovation with government funded R&D programs in the 2010-2013 period. Concerning the services sector, the study of Czarnitzki and Fier (2001) also supported the complementary relationship between public and private R&D for German firms.

2.2. Macro level evidences

To capture the precise effect of public R&D on private R&D expenditure and their knowledge spillovers on the whole economy, it is important to use macroeconomic

¹A similar finding is presented by Coccia (2011).

data (Aghion & Howitt et al, 1998). David, Hall, and Toole (2000) examine whether the public R&D spending crowd-in or crowd-out the private R&D by investigating the literature survey. They conclude that the findings overall are ambivalent and the existing literature as a whole is subject to the criticism that the nature of the "experiment(s)" that the investigators envisage is not adequately specified.

At macro level, Lichtenberg (1987) failed to the significant results between public and private R&D link, while, Levy and Terleckyj (1983), Terleckyj (1985) and Robson (1993) and Diamond (1998) used time-series data and found significant complementary relationship between public and private R&D for US economy. Levy (1990), Von Tunzelmann and Martin (1998) and Guellec and Van Pottelsbergue De La Potterie (2001) use panel data and reported the complementary relationship between public and private R&D for OECD countries as well. According to Becker (2015), public policies are considered within three categories, namely R&D tax credits and direct subsidies, support of the university research system and the formation of high-skilled human capital, and support of formal R&D cooperation across a variety of institutions.

Bloom, Griffith and Van Reenen (2002) examine the impact of fiscal incentives on the level of R&D investment using a panel of data on tax changes and R&D spending in nine OECD countries over a 19-year period (1979-1997). They explored that tax incentives are effective in increasing R&D intensity, even after world macro shocks and other policy influences. Their study estimated a long-run elasticity of R&D with respect to cost of R&D of around -1.0. A similar study by Guellec and De La Potterie (2003) show that R&D tax credit has positive impact on the private R&D by employing macro level data on 17 OECD economies. Within a first difference auto regressive model, government R&D funding (grants and subsidies) is found to significantly enhance business R&D. This study demonstrates an original evidence of an inverted U-shape of the effect of a public subsidy on private R&D, as such as obtaining the strongest private R&D effects for medium average subsidization rates of 4-11%, while rates above 20% are found to be associated with the substitution of government funds for private funds. In a crosscountry analysis, Czarnitzki and Lopes Bento (2012) apply a nonparametric matching method and conclude that private R&D in Belgium, Eastern and Western Germany, Luxembourg and Spain, with the exception of South Africa, benefit from an extension of public R&D subsidies to currently nonsubsidised firms.

Additionally, David et al. (2000), Guellec and De La Potterie (2003) and Becker (2015) stated that the effect of tax credits is more effective than direct subsidies. According to them tax credits have a significant effect on R&D expenditure mainly in the short run, but only little in the long run, whereas subsidies have a positive effect in the medium to long run, but less so in the short run. Based on regression analysis of European countries, Coccia (2010) examines the complementary association between public and private R&D. Thomson and Jensen (2013) study on 25 OECD economies and proposed that most of the R&D expenditure is allocated for R&D staff salaries and for accelerating the business R&D, the government subsidies on R&D will positively influence the private R&D.

Further, a panel study (1970–2002) by Falk (2006) on 17 OECD countries (mostly European) identified the positive and statistically significant impact of tax incentives/ subsidies for R&D and university R&D expenditure on the business R&D (as dependent) using first-differenced system GMM estimation. The long-run elasticity is found to be

approximately -0.9 indicating that a 1% reduction in the price of R&D leads to a 0.9% increase in the amount of R&D spending in the long-run. A similar study presented by Pop-Silaghi et al. (2014) focuses the link between public and private R&D. Their principal finding is based on system GMM analysis, they argued that public R&D does not crowd out private R&D, but there is no statistically significant association between the two variables using macro level data from 1998 to 2008 for Central and Eastern European countries (CEE). Using a macro level data (1988–1912), Markatou and Vetsikas (2015) estimate the effects of innovation in Greece during the crisis. However, their study failed to provide the analysis between public and private R&D. Using generalized structural equation model on EU regions, Kijek, Matras-Bolibok and Rycaj (2016) identified the complementary relationship between public and private R&D. Overall, there is dearth of empirical literature at macro level regarding the public-private relationship in pre and post economic crisis of 2008.

2.3. Conceptual framework

Based on aforementioned studies, we develop a conceptual framework to summarize the R&D policy tool for accelerating the private R&D. Figure 1 shows the impact of R&D as policy tool (government financed R&D) on private R&D using two policy options. First, to accelerate the private R&D, government can provide direct R&D support using fiscal incentives such as grants, subsidies or tax credits and this may stimulate (+) or crowd-out (-) the private R&D. On the right-hand side of the framework, indirect support to R&D

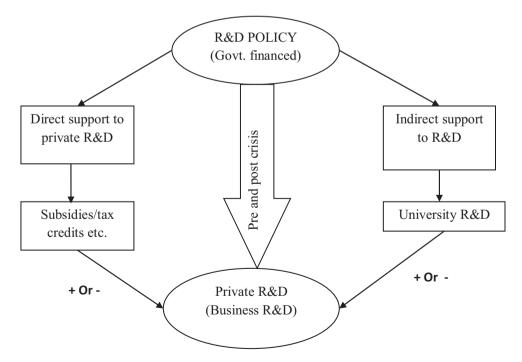


Figure 1. R&D (Govt. financed R&D) policy tools. Source: Compiled by the authors

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through university R&D expenditure (or public labs) may also stimulate (+) or crowdout (-) the private R&D. However, past studies failed to measure the impact of direct and indirect R&D on private R&D in pre and post economic crisis using macro level data. To conclude the review of the literature, we found that there is research gap in terms of analyzing the effect of public R&D on private R&D in pre and post economic crisis of 2008 and also checking the robustness of results across sectors and regions.

3. Source of data

3.1. Methodology

Macro level data is obtained from the OECD website under the heading account "Main Science and Technology Indicators" for 15 years (2000–2014). To estimate the relationship between public and private R&D, the macro level panel data are used. The use of panel data provides edge over times series and cross-sectional data as it combines the characteristics of both types of data. Further panel data study enables us to control the demographic characteristics of each country and allow high degree of freedom.

Data is collected from five European countries, i.e., Germany, France, Italy, Belgium, UK, and 5 Asian countries i.e., Japan, China, Singapore, South Korea and Turkey. This allows us to assess the impact of global economic crisis of 2008 both in European and Asian economies using macro level data. The choice of each country selection is based on two criteria. First, it is decided that not to include those countries which has missing R&D data (public and private) from 2000–2014 (see Table A1). Second, the selection of five EU and five Asian countries is based on their innovation profile which is presented in the global innovation index-2012 report. This report somewhat covers our study period (2000–2014). Further, we also examined the reports from other periods from 2000 to 2014 (one by one) and we found that the rank of these countries does not vary significantly.²

Figure 2 presents the global innovation score between 0 and 100. The higher is the score, the more developed the country is in terms of human capital, infrastructure, business sophistication and creative output. UK has the highest score (61.2) in Europe, followed by Germany (56.2), Belgium (54.3), France (51.8) and Italy (44.5). While in Asian economies, Singapore is with the highest score of 63.5, compared to Japan (51.7), Korea (53.9), China (45.5) and Turkey with lowest score of 34.1. In the global innovation index ranking, Singapore is the top most and then followed by UK, Germany, etc. Comparing the efficiency score among high income countries (based on income per capita), mostly European countries are dominant over Asian high income countries (Japan, Korea and Singapore). This indicates that these 5 European countries are more efficient in goods, labor and financial markets. On the other hand, among middle income

²To provide further evidence regarding the choice of sample based on other reports, the European innovation score board 2019 based on country innovation profile from 2011 to 2018 in terms of human resources, innovation-friendly environment, finance and support, R&D investment, SME innovation and linkages and so forth. Germany is a strong innovator based on property rights, R&D expenditure while, Belgium scores well in SMEs innovation linkages with others and using high level of ICT. Similarly, France and UK are strong innovators in terms human capital, intellectual assets and innovation friendly environment. Italy and Turkey (non-EU member) being moderate innovators have high SMEs product and process innovations. While, the Global Innovation Index 2018 report (see Dutta, Lanvin, & Wunsch-Vincent, 2018) ranked Singapore, South Korea, Japan and China in top 20 most innovative economies in the global rank.

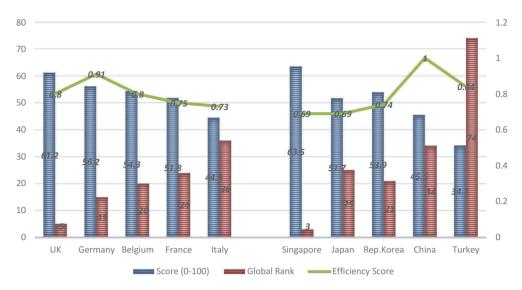


Figure 2. Innovation Index Ranking. Source: Global Innovation Index 2012

countries (China and Turkey), China is higher than Turkey. Overall, these 10 countries have substantial representation in the global innovation index survey of 2012. Further, we checked the global innovation profile in different time periods, as they do not vary significantly.

3.2. Descriptive analysis

Table 1 provides information on key technological innovation indicators which are divided into pre and post economic crisis. The results are calculated in terms of average expenditures for each single indicator for both pre and post economic crisis periods. As we can see in the Table 1, business R&D expenditure (proxy of private R&D), university R&D expenditure and R&D both in manufacturing and services substantially increased from 2008 to 2014 compared to pre-economic crisis period (2000–2007). Substantial investment in R&D immediately after economic crisis indicates that macroeconomic policies are directed in technological advance and in some emerging economies (China and Turkey) to recover the economy faster.

| Innovation indictors | Pre-crisis 2000–2007 | Post-crisis 2008–2014 |
|--|-------------------------|--------------------------|
| Business R&D expenditure (in millions \$) | 26,365.52 | 50,760.81 |
| University R&D expenditure (in millions \$) | 6690.969 | 10,768.19 |
| R&D in manufacturing sector (in millions \$) | 23,345.24 | 44,637.14 |
| R&D in services sector (in millions \$) | 3020.286 | 6123.679 |
| Skilled (R&D workers) (in thousands) | 373,825.4 | 587,712.2 |
| Trademarks (in thousands) | 103,780.2 | 190,507.8 |
| Domestic credit to private sector (% of GDP) | 97.97 | 108.61 |
| Public R&D (government financed) (% of GDP) | 0.5622 | 0.6230 |

Table 1. R&D expenditure pre and post economic crisis.

Data source: OECD

In addition, in these 10 economies the number of R&D workers (on average) is increased from 373,825 to 587,712. There is massive improvement in trademarks applications as well. A similar high-level trend is found for domestic credit growth to the private sector. Specifically, public R&D (percent of GDP) increased from 0.56 to 0.62 percent in the post crisis period. This shows that the role of Keynesian multiplier (through government spending) plays a significant part in determining the technological innovation. In sum, it is concluded that knowledge-based economies on average invested in technological innovation despite the global economic downturn. Generally speaking, technological advance countries boosted the high technology exports and recovered from the crisis effectively.

To add further evidence, Figure 3 shows the cumulative frequency distribution for business R&D expenditure per researcher before and after the financial crisis (see appendix A1). Business R&D expenditure per researcher provides the ratio between R&D expenditure and R&D workers/researchers. R&D expenditure per researcher (or R&D intensity) is a more appropriate measure of investment in technological innovation. Previous studies (e.g., Coccia, 2010; Lach, 2002) use only business expenditures on R&D. The rationale to use R&D expenditure per researcher is that high human capital (number of researchers) attracts greater investment in R&D, creates more technological innovations, and makes the economy more progressive (see Nelson & Edmund, 1966). Additionally, high is the ratio of R&D intensity meaning more investment in technological innovation. Overall, the distribution curve for business expenditure per researcher after the crisis has outweighed the curve before economic crisis (2000–2007). The same high cumulative frequency distribution trend is found for other variables such as government R&D expenditure per researcher (proxy of public R&D) and domestic credit to private sector.

In sum, the distribution curves suggest that these 10 economies increased the investment in private and public R&D immediately after the global economic crisis. Figure 5 shows the cumulative frequency distribution of domestic credit to the private sector both

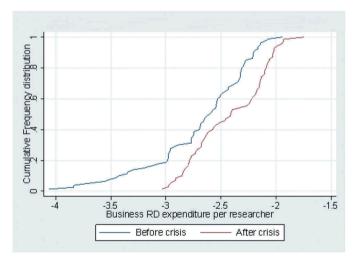


Figure 3. Business R&D expenditure per researcher (before and after crisis).

in pre and post economic crisis of 2008. We can observe that the post crisis curve is

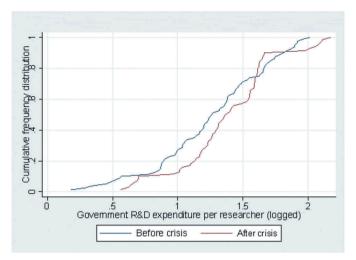


Figure 4. Government R&D expenditure per researcher (before and after crisis).

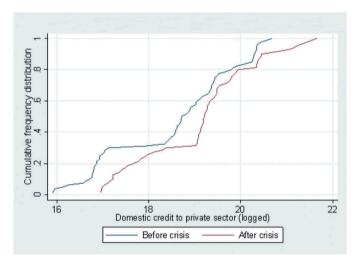


Figure 5. Domestic credit to private sector (before and after crisis).

rightward and indicate that domestic credit is increased in post economic crisis to support technological innovation by using effective financial system. In addition, Figure 6 reports the public and private R&D expenditure per researcher along with economic growth from 2000 to 2014 for every single country. The Figure 6 present that most of the economies experienced downturn in 2008,³ while public (government financed) and private R&D expenditure per researcher showed linear curves. This indicates that these 10 economies have persistently invested in technological innovation i.e., without halting R&D during the time of crisis.

³While Turkey also faced a low output in 2001 due to political instability and financial crisis (currency crisis in Turkey in 2001), this study neglected that specific crisis because it was not observed across other countries in our dataset.

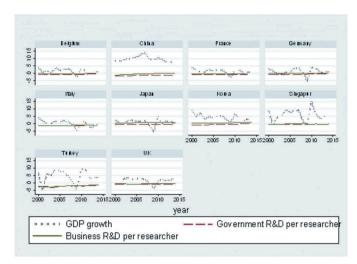


Figure 6. R&D expenditure (Business and Govt) and growth.

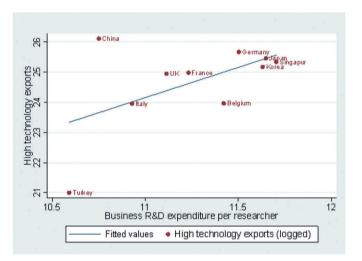


Figure 7. Business R&D expenditure and high technology exports.

Concerning investment in knowledge-based capital (R&D) and its effect on high technology exports, Figure 7 presents the link between high technology exports (electronics, IT and pharmaceuticals) and business R&D expenditure per researcher. The graph shows that on average Germany, Japan, Singapore, Korea are relatively better in terms of high technology exports and business R&D investment. This scatterplot indicates that business R&D per researcher drives high technology exports. However, Turkey has comparatively weak investment in R&D per researcher which results in low exports for high technology products. Further, public support (or government) to R&D is not sufficient; and the credit market plays vital role in boosting the technological innovation output. For example, Hsu, Tian, and Xu (2014) suggest that countries with high financial

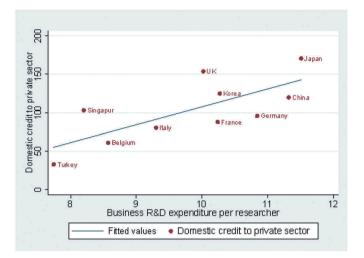


Figure 8. Business R&D and domestic credit (logged).

development (high credit to the private sector) accelerate technological innovation because R&D is costly and risky and require financial support.

Figure 8 shows the cross-country relationship between business R&D expenditure per researcher and credit to private sector. The figure suggests that China, France, Germany, Japan, Korea and UK provide relatively more credit to the private sectors with higher business R&D expenditure per researcher. According to the 2013 global financial centers index, UK (London), Germany (Frankfurt), Japan (Tokyo), Korea (Seoul), France (Paris) are high-ranked cities in terms of most developed financial sector and with ease of doing business. Once again Turkey (Istanbul) has a relatively weak credit market which result in low investment in business R&D expenditure per researcher. Overall, Figure 8 suggests that countries with a more developed financial sector are more likely to finance business R&D per researcher.

3.3. Econometric model

In order to examine the link between public and private R&D expenditure in pre and post economic crisis, system generalized method of moments (GMM) is preferred over ordinary least squares (OLS) for a number of reasons. First, the causality may run between business R&D expenditure per researcher and other explanatory variables such as university R&D expenditure per researcher and so forth. Second, the fixed effects such as demographic characteristics (e.g., size and growth of each country) may have correlation with unobserved term. Third, the presence of lagged dependent variable (business R&D) may cause autocorrelation. All these three issues along with panel data from 2000 to 2014 emphasize to use GMM estimation. Regarding the use of small sample size (in our case) in system GMM estimation, studies (e.g., see Soto, 2009) indicated that system GMM even with relatively small sample size (N = 100, 50, 35) produced efficient estimates for country specific growth studies. To check system GMM effectiveness in small sample size, Soto (2009) used Monte Carlo Simulation to analyze the performance of system GMM and found low biased root mean square error (RMSE) for estimates (α and β). This outcome showed that small sample size in system GMM provides low biased estimates in panel studies. Overall, system GMM displays less biased and high precision estimators in small sample size compared to OLS estimators.

For addressing the causality, autocorrelation and endogeneity problem in the panel models, Arellano and Bond (1991) and Holtz-Eakin, Newey, and Rosen (1988) propose to use first difference GMM estimation instead of OLS estimation. This estimation method provides unbiased estimators compared to 2SLS regression (based on OLS) and used lagged-dependent variable (business R&D intensity per researcher) as an instrument. In sum, system GMM estimation removes endogeneity, fixed country-specific effects and correlation of lagged dependent variable with insignificant error. Regarding empirical strategy, this paper first analyzes the relationship between public and private R&D expenditure excluding the effect of economic crisis and then examines the robustness of the results in pre and post economic crisis period. Equation 1 reports the first difference GMM estimation (all variables are logged, see appendix A1 for detail). To minimize the endogeneity problem due to omitted variable bias and improving the causal interpretation of the estimated coefficients (see Klarmann & Feurer, 2018), we used control variables such as domestic credit to private sector (CREDIT_PW), intellectual property rights (proxy by trademarks applicants i.e., TRADE_MARK_PW) and skilled labor (R&D workers i.e, SKILLED_LAB). Studies (e.g., Caporale, Rault, Sova, & Sova, 2015) single out financial development as key indicator to accelerate economic growth. For instance, the study of Hsu et al. (2014) pointed out that developed credit markets accelerate the technology innovation in economies with high-tech industries. We used domestic credit to private sector as the proxy of financial development and expect that effective financial system (through domestic credit) will increase the technological innovation in the private sector (private R&D intensity). In addition, we used trademark (use of specific word and/or symbols) applications as regressor (see Rehman & Yu, 2018) in the model for two possible reasons; first, more trademark applications will increase the incentive to invest R&D in the private sector. Second, it will maintain the quality of innovation (driven by R&D) in the private sector. In other words, countries with strong intellectual property rights are more likely to engage in R&D activities and accelerate performance (see Falk, 2006). Further, the skilled labor force (R&D workforce) is used as a proxy of human capital. It is widely discussed in the literature that economies with high quality of labor force (or workers in science and technology) strongly favors the innovation activities. Such high human capital is responsible to implement new technology efficiently and adapt the new learning environment effectively. Equation 2 presents the differencing of fixed country-specific effects.

$$\Delta logPVT_RD_INT_{i,t} = \varphi \Delta logPVT_RD_INT_{i,t-1} + \beta_1 \Delta logPUB_RD_INT_{i,t} + \beta_2 \Delta logUNI_RD_INT_{i,t} + \beta_3 \Delta logCREDIT_PW_{i,t} + \beta_4 \Delta logSKILLED_LAB_{i,t} + \beta_5 \Delta logTRADE_MARK_PW_{i,t} + \Delta \mu_{i,t}$$
(1)

$$\Delta \mu_{it} = \Delta \nu_i + \Delta e_{it} \tag{2}$$

Table 2 provides relationship between public and private R&D intensity.⁴ The lagged dependent variable (private R&D intensity) shows significant and positive association

| Private R&D intensity-depend. | Coefficient | Coefficient | Coefficient |
|-------------------------------|------------------|------------------|------------------|
| | - | Manufacturing | Services |
| Private R&D intensity $(t-1)$ | 0.545***(0.118) | 0.354***(0.130) | 0.105***(0.048) |
| Public R&D intensity | -0.066(0.135) | 0.3133***(0.115) | 0.726***(0.116) |
| University R&D intensity | 0.215***(0.073) | 0.0341(0.1092) | 0.0163(0.142) |
| Domestic credit per worker | 0.242**(0.130) | 0.323**(0.147) | 0.297***(0.126) |
| Skilled workforce | -0.103(0.129) | 0.369***(0.060) | -0.312**(0.122) |
| Trademark per worker | 0.039(0.044) | -0.091**(0.042) | -0.184***(0.063) |
| Constant | -3.587***(1.940) | -3.051***(0.883) | -1.8795*(1.151) |
| Observations | 140 | 140 | 140 |
| Wald Chi2 (6) | 18,948.23*** | 10,446.11*** | 2799.48*** |

Table 2. Dynamic panel model using system GMM.

***/**/* significant at 1%/5%/10%. Robust standard errors are presented in parentheses.

with private R&D intensity in the current period (see appendix A1 for variable definitions). The lagged dependent variable somewhat provides reasonable result with less biased magnitude of the coefficient compared to OLS (ordinary least square). For example, private R&D intensity might be correlated with error term. To reduce endogeneity problem, system GMM uses lagged of dependent variable as an instrument (see Arellano & Bond, 1991). In other words, past R&D investment in the private sector likely to stimulate more R&D in the current period. Countries with past R&D history are more likely to increase their investment in future. In the second column of Table 2, there is no significant relationship between public and private R&D intensity. When splitting the data into sectors, we found that the elasticity of public R&D is significant in both manufacturing and services sectors. The respective significant coefficient 0.3133 and 0.727 showed strong evidence of complementary relationship between public and private R&D intensity. This results hence support the prior empirical findings of Coccia (2010), Thomson and Jensen (2013) and Falk (2006) which confirmed the complementary association.

While university R&D intensity presents significant and positive association with private R&D intensity, this relationship is not robust across sectors. The elasticity of skilled labor ($\beta = 0.369$, *p*-value = 0.01) positively influence the private R&D intensity in manufacturing sector, while negative ($\beta = -0.312$, *p*-value = 0.01) in the services sector. This finding suggests that more skilled labor in the manufacturing sector accelerates the private R&D intensity. However, high wages in the services may reduce the R&D expenditure per researcher in the services sector. Further, trademark per worker shows that the cost of innovation (registration of trademarks) reduces the private R&D intensity. In order to estimate the two hypotheses, we split the data into pre and post economic crisis and also across sectors and regions.

3.4. Analysis for pre and post economic crisis period

As discussed earlier none of the previous studies explored the association between public and private R&D while taking into the account of pre and post economic crisis of 2008. This study is novel in terms of empirical approach to revisit the public and private R&D link and draw policy implications. System GMM estimation is used for pre (2000–2007) and post economic crisis (2008–2014). To examine the coefficients of public R&D

⁴From now on, we used private R&D intensity instead business expenditure per researcher.

whether they are equal or not in pre and post economic crisis, we deployed Chow test (Chow, 1960) on public R&D (by merging both government and university R&D expenditure per worker).⁵ Based on Chow test value, we rejected the null hypothesis of equal coefficients across two periods and conclude that our public R&D coefficients are not the same in pre and post economic crisis of 2008 (see Table 3–5). In other words, it is evident that we have a structural break in public R&D intensity due to economic crisis of 2008. In short, the choice of splitting the data into pre (2001–2007) and post (2008–2014) for estimation followed the econometric procedure. Further, to check the potential serial correlation problem, Arellano and Bond test with second order (AR2) do not reject the null hypothesis based on low z-values (or p-value>0.05) which indicates that our models do not suffer from serial correlation. To examine the over-identifying restriction, the Sargan test also fails to reject the null hypothesis based on low Chi2 values (or *p*-values>0.05) and suggests that over-identification is not a problem in our models. In sum, the choice of splitting the data into two series (pre and post crisis) provides the varying coefficient. After passing important diagnostic tests, we can continue our empirical analyses comparing the results before and after the economic crisis of 2008.

Table 3 provides information on public and private R&D link using sector wise macro level data. In the second column, parameters are reported before economic crisis (2000–2007). The first variable, lagged dependent variable of private R&D expenditure intensity, positively influence the private R&D expenditure intensity. However, this effect disappears in post economic crisis and also in the services

| | Manufacturing sector | | Services sector | |
|------------------------------------|---------------------------|-----------------------------|---------------------------|----------------------------|
| | Pre-Crisis (2000–2007) | Post- Crisis (2008–2014) | Pre-Crisis (2000–2007) | Post-Crisis (2008–2014) |
| Private R&D intensity as dependent | Coefficients | Coefficients | Coefficients | Coefficients |
| Private R&D intensity (t-1) | 0.1759* | 0.3163** | 0.0244 | 0.3132** |
| · | (0.1125) | (0.1479) | (0.0341) | (0.1368) |
| Public R&D intensity | 0.5986*** | 0.2375** | 0.8722*** | 0.4671*** |
| | (0.1242) | (0.1129) | (0.0503) | (0.1473) |
| University R&D intensity | 0.0469 | 0.1782** | 0.0379 | 0.0473 |
| | (0.1317) | (0.0847) | (0.1431) | (0.0959) |
| Domestic credit per worker | 0.3714** | 0.0772 | 0.2964*** | 0.1395 |
| | (0.1317) | (0.1449) | (0.0790) | (0.0898) |
| Skilled workforce | 0.5334** | 0.6476*** | -0.2856** | -0.1908* |
| | (0.2123) | (0.0986) | (0.1132) | (0.1025) |
| Trademark per worker | -0.1851*** | -0.0521** | -0.2371*** | -0.1062** |
| | (0.0566) | (0.0239) | (0.0404) | (0.0535) |
| Constant | -2.8946** | -1.2399 | -1.6853* | -0.6784 |
| | (1.2970) | (0.8968) | (1.0142) | (0.6576) |
| Number of observations | 70 | 70 | 70 | 70 |
| Number of groups | 10 | 10 | 10 | 10 |
| Wald Chi2 | 4028.71*** | 3548.75*** | 1369.38*** | 1753.78*** |
| Chow test (Chi2) | 9.50*** | 6.62** | 18.33*** | 11.87*** |
| Autocorrelation test | -0.9573 | -0.9427 | -0.2885 | -0.8574 |
| Sargan test | 6.6906 | 6.0828 | 6.7708 | 6.9747 |

Table 3. System dynamic panel data estimation (GMM), sector wise analysis.

***/**/* significant at 1%/5%/10%. Robust standard errors are presented in parentheses.

⁵The focus of the paper is to examine the link between public and private R&D. So, based on our research question, we generated two interactive variables (public R&D multiplied by pre crisis dummy) and the second one (public R&D multiplied by post crisis dummy) for Chow test. This test is deployed also across sectors and regions.

sector. The elasticity of public R&D ($\beta = 0.5986$; *p*-value = 0.01) has positive impact on the private R&D intensity in pre economic crisis. In sum, the outcome of public and private R&D link is robust across sectors in both pre and post economic crisis (see Table 3). However, the strength of their complementary relationship is low in post economic crisis. Despite the fact of their complementary relationship, the outcome suggests that the ratio of R&D expenditure to R&D workers were low in manufacturing and services sectors in post economic crisis of 2008. The parameter of university R&D expenditure per researcher ($\beta = 0.1782$; *p*-value = 0.05) shows positive and statistically significant link to private R&D intensity only in manufacturing sector after the economic crisis.

Domestic credit to private sector per worker shows that in pre-economic crisis sector, credit to private sector accelerates the private R&D both in manufacturing and in services sector but there is no link found post the economic crisis. In manufacturing sector, high skilled labor force (number of scientists) shows positive influence on the private sector R&D, while in the services sector the relationship is the opposite. This outcome indicates that skilled labor reduces the business R&D intensity due to high wages. Trademarks introduced by manufacturing and services negatively influence the private sector R&D which implies that cost of introducing intellectual property reduces the private sector R&D.

3.5. Regional analysis (Europe vs. Asia)

Table 4 provides information related to the link between public and private R&D by splitting the data into regions i.e., Europe and Asia across manufacturing sector. By looking into the estimated parameters, we found that the elasticities of public R&D intensity are only positive and significant in post economic crisis in the European countries. While, the relationship between public and private R&D intensity is found positive and significant in both pre and post economic crisis for Asian countries. In addition, by comparing the parameters across Europe and Asia, we identified that the complementary relationship is strong for Asian economies. This outcome indicates that the economic crisis effects the European countries more compared to Asian economies. This finding supports that public R&D per researcher accelerates private R&D per researcher in pre and post economic crisis, but the impact has been found weak for Europe. R&D spending per researcher by universities positively influences the private sector R&D and implies that whether R&D from government or through universities will accelerate the private sector R&D. The coefficient of domestic credit to the private sector shows positive and significant association for Asian countries both in pre and post economic crisis of 2008. This outcome indicates that Asia credit markets supported the technological innovation in the private sector. The high human capital which is measured through the number of R&D workers (proxy of skilled workforce) positively affect the private R&D intensity. This result apparently suggests that high human capital encourages technological innovation in the private sector.

Lastly, Table 5 reports the results related to public and private R&D association in pre and post economic crisis of 2008 for Europe and Asia in the services sector. The results are somewhat consistent to the previous findings from Tables 3 and 4. Public R&D intensity shows a statistically significant and positive link with private sector R&D per

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| | Manufacturing sector-Europe | | Manufacturing sector-Asia | |
|------------------------------------|-----------------------------|----------------------------|---------------------------|----------------------------|
| | Pre-Crisis (2000–2007) | Post-Crisis (2008–2014) | Pre-Crisis (2000–2007) | Post-Crisis (2008–2014) |
| Private R&D intensity as dependent | Coefficients | Coefficients | Coefficients | Coefficients |
| Private R&D intensity | 0.5121*** | 0.3923*** | 0.1970** | 0.1685* |
| (t-1) | (0.1520) | (0.0726) | (0.0953) | (0.1014) |
| Public R&D intensity | 0.1300 | 0.1958*** | 0.4850*** | 0.4033*** |
| | (0.1146) | (0.0561) | (0.1312) | (0.1012) |
| University R&D intensity | 0.2454*** | 0.3194*** | 0.2495* | 0.0882 |
| | (0.0490) | (0.0420) | (0.1488) | (0.1284) |
| Domestic credit per worker | 0.0599 | 0.0774 | 0.3578*** | 0.2416*** |
| · | (0.0656) | (0.0529) | (0.1393) | (0.1033) |
| Skilled workforce | 0.5936*** | 0.6813*** | 0.6178*** | 0.6204*** |
| | (0.1423) | (0.1057) | (0.1792) | (0.1839) |
| Trademark per worker | 0.0404 | 0.0927 | -0.0933 | -0.0631* |
| | (0.0675) | (0.0634) | (0.1141) | (0.0338) |
| Constant | -2.4484*** | -2.2795*** | -3.7677*** | -2.2561** |
| | (0.6424) | (0.4401) | (1.3069) | (0.5861) |
| Number of observations | 35 | 35 | 35 | 35 |
| Number of groups | 5 | 5 | 5 | 5 |
| Wald Chi2 | 1636.18*** | 454.74*** | 61.32*** | 750.37*** |
| Chow test (Chi2) | 5.82*** | 5.59*** | 10.61*** | 6.15*** |
| Autocorrelation test | 0.4019 | -1.7492 | -1.4830 | -0.7076 |
| Sargan test (Chi2) | 6.63011 | 6.4122 | 6.6877 | 6.0458 |

| Table 4. System dynamic panel data estimat | tion (GMM), regional analysis. |
|--|--------------------------------|
|--|--------------------------------|

***/**/* significant at 1%/5%/10%. Robust standard errors are presented in parentheses.

| | Services sector- Europe | | Services sector-Asia | |
|----------------------------|---------------------------|----------------------------|---------------------------|----------------------------|
| | Pre-Crisis (2000–2007) | Post-Crisis (2008–2014) | Pre-Crisis (2000–2007) | Post-Crisis (2008–2014) |
| Private R&D intensity | Coefficients | Coefficients | Coefficients | Coefficients |
| Private R&D intensity(t-1) | 0.0243 (0.0950) | 0.3923*** (0.0726) | 0.0140 (0.0296) | 0.1383* (0.0596) |
| Public R&D intensity* | 0.9531*** | 0.1958*** | 0.9624*** | 0.6187*** |
| University R&D intensity | (0.0604) 0.2597 | (0.0561) 0.3194*** | (0.0289) -0.1260 | (0.0997) 0.0284 |
| Domestic credit per worker | (0.2121) 0.0861 | (0.0420) 0.0774 | (0.0833) 0.0736 | (0.1276) 0.2345*** |
| Skilled workforce | (0.2417) -0.1609 | (0.0529) 0.6813*** | (0.1637) 0.0495 | (0.0781) 0.2859*** |
| | (0.3962) | (0.1057) | (0.2169) | (0.1091) |
| Trademark per worker | -0.0509 (0.1667) | 0.0927 (0.0634) | -0.2137*** (0.0410) | -0.1602*** (0.0329) |
| Constant | 1.6815*** (0.3556) | -2.2795*** (0.4401) | 1.0723 (0.7792) | -1.3408*** (0.5827) |
| Number of observations | 35 | 35 | 35 | 35 |
| Number of groups | 5 | 5 | 5 | 5 |
| Wald Chi2 | 388.91*** | 454.74*** | 67.32*** | 2937.51*** |
| Chow test (Chi2) | 5.31*** | 5.67*** | 9.10*** | 7.01*** |
| Autocorrelation test | -0.7950 | 0.5458 | -0.5963 | 0.5523 |
| Sargan test | 6.3201 | 6.8866 | 6.9781 | 6.3122 |

Table 5. System dynamic panel data estimation (GMM), regional analysis.

researcher in pre and post economic crisis. The results are found strong for Asian economies and clearly indicate that economic crisis effected Europe more than Asia. Moreover, in the services sector, R&D expenditure per researcher by universities overall showed weak evidence compared to manufacturing sector. This finding goes in the favor

of the European countries in terms of university-industry linkages. Trademark per workers showed negative association to private R&D intensity only for Asia.

4. Conclusion

R&D budgets are often reduced during the time of economic crisis due to its risky nature and long-term investment. Considering the importance of business R&D, in prolong recession the financial sector is even reluctant to finance the R&D projects because of high degree of uncertainty even if they are successfully operating (Brockhoff & Alan, 1998). In such circumstances, the role of public sector is essential to support technological innovation in the private sector. By financing the private sector R&D through government financed R&D schemes such as tax credits, grants and subsidies spur the technological innovation in the private sector of an economy. In other words, public R&D support program is a good strategy to keep innovating the economy during the time of low business fluctuations. To the best of our knowledge, very few empirical studies have been conducted to investigate the public–private R&D link at macro level in pre and post economic crisis of 2008. This study has contributed to the empirical literature in this regard.

To conclude our principal findings based on system GMM estimation across European and Asian economies, we found that public R&D complement private R&D in pre and post economic crisis of 2008. This outcome is robust and strong across manufacturing sector particularly in the pre-crisis period. Further, the complementary association is found overall in both regions and in both sectors. However, the ratio of R&D expenditure to total R&D workers has been somewhat reduced in post economic crisis compared to pre-crisis across European and Asian countries. Overall, our findings implied that increased in government financed R&D helped the private sector investment in R&D immediately after the crisis. While, the impact of public R&D on private R&D per researcher identified strong for Asian economies than for European countries. Apparently, this result indicates that Asian economies were less exposed to the economic crisis. Concerning the impact of university R&D intensity on private R&D intensity, European economies are superior in terms of university-industry linkages for boosting technological innovation.

We extracted important policy implications based on this empirical study. To counter the economic crisis effectively, specific government financed R&D schemes such as tax credits, R&D grants, subsidies will boost the technological innovation in the private sector. Based on our analysis across European and Asian countries, it is strongly recommended that if we invest in R&D through public support programs (fiscal incentives), this strategy will boost technological innovation in the private sector. Alternatively, the role of Keynesian multiplier (through increased spending) is an important factor to drive the technological innovation in the private sector during the time of economic downturn. To devise specific policy regarding R&D expenditure, the policy makers should consider the public support to R&D based on the ratio between R&D expenditure and R&D workers at industry level. If one R&D worker is to be hired, the amount of related R&D should be calculated and invested accordingly. Further, the financial development (domestic credit to the private sector) should promote the technological innovation in the private sector through effective lending in the needy sectors 368 👄 N. U. REHMAN ET AL.

of the economy. Overall, our results are robust for university R&D intensity and Private R&D in European economies and this showed that there is strong research linkage between universities and industry. We can extend this finding to other countries in Asia by making university-industry linkages for increasing technological innovation. Concerning the limitations of the paper, future studies may extend public and private R&D link in pre and post economic crisis using micro level large panel data. Further, the effect of public–private R&D link on economic growth must be taken into account in the future research work.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

| Variables | Definitions |
|---------------------------------|--|
| Private R&D intensity | Log (business R&D expenditure/R&D workers) |
| Public R&D intensity* | Log (Government financed R&D expenditure/R&D workers) |
| University R&D intensity | Log (University R&D expenditure/number of R&D workers) |
| Business R&D intensity- serv.* | Log (Business R&D in services sector/R&D workforce) |
| Business R&D intensity- manuf.* | Log (Business R&D in manufacturing sector/R&D workforce) |
| Public R&D intensity- services* | Log (Public R&D in services sector/R&D workforce) |
| Public R&D intensity- manuf.* | Log (Public R&D in manufacturing sector/R&D workforce) |
| Domestic credit per worker | Log (domestic credit to business sector/total workforce) |
| Skilled workforce | Log (number of scientists in R&D) |
| Trademark | Log (number of trademarks per worker) |

Table A1. Variables and their definitions.^{1.}

*Figures were initially provided in percent of GDP and it is calculated by multiplying with GDP – PPP.
¹All variables have been adjusted with inflation using annual CPI data from 2000–14, we selected 2000 as based year.