THE CONSEQUENCES OF THE GREAT RECESSION FOR THE R&D SHARE OF INVESTMENT IN THE EUROPEAN UNION

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Abstract
In this paper we investigate the medium term dynamics of the R&D share of total investment in the European Union over the Great Recession. Our results show that the crisis disclosed a dualism inside the EU, consisting of two dissimilar areas Core and Periphery, while in Central Eastern countries the crisis activated a peculiar pattern from which few early signs of convergence towards the Western side of the EU are recognizable. Only the Core turns out to be an integrated area in which credit markets, industrial base and R&D policy favoured a countercyclical reaction of the R&D share to the impact of the crisis. In both Periphery and Central Eastern countries the crisis did not prompt a relevant change in the composition of investment in favour of a higher share of innovation. However, while in the Periphery the pattern of the R&D share appears a forewarning signal for further divergence over the medium term, in the Central Eastern area the dynamics of the industrial base and the emergence of a sound relationship between innovation and credit in the period following the crisis, suggest that the response to the crisis laid the basis for a renewed process of accumulation.

Keywords: R&D investment; European Union; economic crisis
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I. Introduction

The most incisive European institutional response to the crisis is *Europe 2020*, drawn up by the EU Commission in 2010. This document, and the flagship initiative *Innovation Union* contained therein, outlines a strategy for boosting research and innovation as a necessary condition to launch a prospect of smart growth and to start a renewed social and territorial cohesion inside the EU. The accomplishment of this goal, alongside of other related initiatives included in *Europe 2020*, involves a complex policy design, aimed at improving the financial system for a more affordable access to finance, at supporting the restructuring of the industrial base and the transition of manufacturing sectors to a greater resource efficiency, and at targeting government towards an active industrial policy and the priority of knowledge expenditure to promote R&D investment. The document explicitly recognises that the crisis underscored the close links between national economies combined with divergent macroeconomic performances. Therefore, to cope with the objectives of Europe 2020 it is stressed the need to accomplish reinforced policy coordination at European, national and regional levels.

The evaluation of the medium term prospects hoped for and expected by the gradual implementation of the *Europe 2020* objectives, should take into account further

questions related to the effectiveness of R&D policy in the post-crisis period. To clarify the issues at stake, consider that it is well established a relation between credit market and R&D investment. However, how did the crisis impact on this relationship? Is the sensitivity of innovation activity to financial market the same as in the pre-crisis period, or did it change as a result of the 2008-2009 credit crunch? Similarly, *Innovation Union* stresses that national governments should promote greater private R&D investment by using tax incentives and subsidies. In this respect, did the crisis affect the ability of these policy instruments to encourage private innovation? In particular, with respect to the pre-crisis period, should R&D subsidies be expected to be a substitute for private expenditure or to have multiplicative effects by stimulating the business sector to undertake additional innovation effort? Finally, *Europe 2020* clearly underlines that a new economy based on knowledge and innovation must be sustained by a proper transformation of the industrial base with particular emphasis on manufacturing. Again, to what extent did the wiping out of the crisis impact on the link between innovation and industrial structure? *Europe 2020* stresses the crisis as a permanent break that wiped out not only the economic gains of growth achieved since the 2000s, but the whole engine of growth at work over the last decade. Combined with the need to envisage a new pattern of growth through a tremendous effort to renovate the stock of productive knowledge, this view clearly echoes a creative-destruction argument. Even if not explicitly mentioned inside the document, the above consideration raises an additional question. To what extent did the crisis prompt across different EU areas a countercyclical reaction in terms of an enhanced propensity to undertake innovation activity? This question has also relevant implications for the policy framework devised in Europe 2020. Not only a heterogeneous reaction of R&D investment may foster further divergence in the EU area over the medium term, but may crucially affect the effectiveness of policy measures directed to productivity-enhancing investment.

The questions raised so far motivate the empirical analysis developed in this paper, aimed at examining the dynamics of innovation in Europe before and after the crisis. Despite the relevance of the above issues, a limited body of literature investigated the effects of the crisis on innovation activity inside the EU, focusing on specific aspects related to the role played by credit market and to the effects of public support to R&D. In addition, few papers explore the R&D response to the crisis along a

creative-destruction argument. By considering a sample of EU firms over the period from 2004 to 2013, Guney, Karpuz and Ozkan (2017) study the effects of credit lines on R&D investment. They show that firms continued to rely on credit lines over the crisis as a way to finance R&D projects and argue that credit lines provide liquidity insurance when external capital markets are more restricted. Furthermore, they do not observe any significant difference in terms of the influence of credit lines on R&D in the periods before and after the crisis. Focusing on R&D and non R&D firms in Central and Eastern EU countries, Männasoo and Hein (2017) investigate how credit frictions impacted on R&D during the crisis (2007-2009) and in the post-crisis period (2012-2014). They find that, although the financial crisis strongly weakened R&D investment, in terms of share of loan applications accepted, R&D companies had become relatively more viable in the after-crisis period[1]. As far as public R&D policies are concerned, Izsak and Radošević (2017) find that in Northern EU zone the crisis induced increased public support to R&D activities, in the Southern area it caused the crash of government R&D policies, only partially compensated by EU structural funds, while in Central and Eastern EU countries the public frame sustaining innovation, benefitting from a much stronger compensation effect, overall held on. On the wake of this evidence, Izsak and Radošević (2017) conclude that the innovation policies in the aftermath of the crisis induced potential divergence between North and South EU areas, while they prompted convergence between the Northern and Central Eastern sides of Europe. By exploring the pattern of government science and technology budgets, Makkonen (2013) highlights that the crisis impacted more heavily in Eastern and Southern countries than in other EU members[2]. Finally, Archibugi, Filippetti and Frenz

[1] The effect of banking crises on R&D investment is investigated within a broad sample of 51 countries over 1993-2008 by Meierrieks (2014). The author shows that higher levels of financial development correlate with stronger innovation activity, and, in line with the evidence of Guney, Karpuz and Ozkan (2017), that banking crisis, included that of 2007-2008, did not influence negatively R&D. The empirical analysis of Brown, Martinsson and Petersen (2012) offers an explanation of both facts. By considering a sample of EU firms over the period 1995-2007, they show that firms tend to build a buffer stock of liquidity to ensure a smooth path of R&D. As a consequence, firms may display little sensitivity to finance shocks in the short run while, in the longer run a positive relation between R&D and financial development arises.

[2] In the specific case of Germany, Brautzsch et al. (2015) analyse to what extent R&D subsidies counteracted the impact of the crisis, recognizing their positive effects on macroeconomic performance, while Hud and Hussinger (2015) explore the effect of subsidies on private R&D undertaken by small and medium size firms during the crisis, finding evidence of crowding-in.

(2013) test the hypothesis of a Schumpeterian reaction to the crisis in a sample of European firms, finding evidence that over the crisis firms displayed an innovation behaviour closer to a creative destruction pattern, while before the crisis it was more consistent with a technological accumulation hypothesis. Underlining the uneven effect of the crisis on innovation behaviour at European level, Filippetti and Archibugi (2011) focus on specific characteristics of European national systems of innovation and find that the quality of human resources, the specialization in high-tech sectors and the development of the financial system are structural factors able to offset the negative impact of the crisis on R&D investment.

Overall, this limited body of literature shares the view that the crisis prompted a remarkable heterogeneous response of private R&D investment, pointing to several factors that may have influenced the innovation performance of EU countries. With respect to this literature we offer a general macroeconomic view of the effects of the crisis on innovation across the EU. Our empirical analysis investigates the pattern of the R&D share of total private investment over the period 1999-2014 in the EU, considering separately three groups of countries, the Northern side of the EU, labelled as Core, the Periphery sample, which includes the Southern EU members plus Ireland, and the Central Eastern EU countries. In the specific, we look into the relation linking the R&D share of total investment to credit conditions, industrial base and R&D government funding in order to check if the crisis changed the response sensitivity of the R&D share to each of these factors. Moreover, we explore the co-movement between the R&D share and economic growth, focusing on the consequences due to the break of the crisis. It is important to stress that the time horizon of our analysis is based on a medium term perspective. Indeed, the 2008 crisis can be viewed as the downturn stage of an amplified cycle, which from the peak of the early 2000s declines till the collapse of the Great Recession and then starts recovering after 2010. Therefore, inside our sample period it is recognizable a “medium-term” cycle according to the definition proposed by Comin and Gertler (2006). In this extended time perspective the correlation analysis between R&D share and GDP growth does not focus on the longer term consequences of short term cyclicality of the R&D share (Aghion et al. 2010, Barlevy, 2007), but on the propensity of the composition of investment to react to persistent changes in the evolution of macroeconomic conditions. Indeed, by departing

from short run volatility of variables, the composition of investment between R&D and physical capital gains an appealing interpretation. Investment in physical capital can be viewed as the flow expenditure that supplies aggregate technology with productive knowledge accumulated in the past, while R&D investment represents the flow fuelling aggregate technology with novel knowledge in the future. Therefore the composition of investment represents a crucial property of aggregate technology, measuring to what extent an economic system provide resources to escape from diminishing returns and to ensure a steady growth. In this respect, since the R&D share of investment measures the relative tendency to renovate the engine of growth with novel knowledge, it appears an appropriate indicator of the endogenous mechanisms able to preserve and sustain a path of potential growth.

Our results show that the crisis disclosed a dualism inside the EU, consisting of two dissimilar areas Core and Periphery, while in Central Eastern the crisis activated a peculiar pattern from which few early signs of convergence towards the Western side of the EU are recognizable. In the Core the credit market appears, both before and after the crisis, an effective medium to shape an intertemporal path of innovation as to render the medium term dynamics of the R&D share countercyclical. This property of the composition of investment seems to affect the effectiveness of R&D policy, signalled by the enhanced sensitivity of private R&D expenditure to public funding in the post-crisis period. Furthermore, the industrial structure appears capable to activate changes consistent with a creative destruction mechanism on the weak of a persistent downturns. In both Periphery and the Central Eastern countries the crisis did not prompt a relevant change in the composition of investment in favour of a higher share of innovation. However, while in the Periphery this pattern seems to depend on the weakness of the frame linking the dynamic of the composition to credit market, R&D policy and industrial structure, in the Central Eastern area it should be evaluated in the light of the transitional dynamics at work since the accumulation process started in this area in the early 2000s. In particular, the enhanced sensitivity of the R&D to the dynamics of the industrial base and the emergence of a sound relationship between innovation and credit in the period following the crisis, suggest that the response to the crisis laid the basis for a faster convergence process towards the Western side of Europe.

The paper is organized as follows. Section II describes the empirical analysis and the econometric methodology used. The estimation results are presented in section III, while a final discussion is provided in section IV.

II. Empirical Analysis

The empirical analysis developed in this paper aims at examining the pattern of the composition of private investment - in terms of the R&D share of private investment - in the European Union before and after the Great Recession, by taking into account several factors that may shape innovation share: the likely co-movement with the general macroeconomic conditions, government incentives to R&D, industrial structure and credit markets.

Data Description

The country sample consists of 24 EU members over the period 1999-2014. In order to evaluate the impact of crisis across the EU, we split the EU24 sample into three groups labelled Core, Periphery and Eastern. In the Core we include those countries strongly rooted in the history of the EU: Austria, Belgium, Denmark, Finland, France, Germany, Netherland, Sweden and United Kingdom. According to a large body of literature, in the Periphery sample we consider Greece, Ireland, Italy, Portugal and Spain. Finally, the Eastern sample includes Central and Eastern European countries, which joined the EU since 2004: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

As a measure of the composition of investment in terms of R&D share of private investment we consider the ratio between Total intramural R&D expenditure undertaken and funded by the business sector and Total fixed gross capital formation. The overall macroeconomic dynamics is captured by the rate of growth of real GDP, while public incentive to R&D is measured by the Government funding to innovation in the business sector[3] as a percentage of Total government expenditure. Moreover, specific industry characteristics significantly affect the innovation pattern. At macro level a suitable measure of the industrial structure is the ratio between low- and high-

[3] This variable is available in the Eurostat database for all countries with some missing values. The 1999-2001 values for Austria and the 2008-2010 values for Greece have been filled by using the growth rates of total government expenditure in R&D. In other few cases a single missing value has been replaced with the average between values next to the missing one.

tech industries. Unfortunately, this indicator is not available for our set of countries over the whole period 1999-2014. Therefore, we employed as a proxy the ratio between the values added in non-manufacturing and manufacturing sectors[4]. All the above data comes from the Eurostat database. Furthermore, in order to evaluate the relevance of credit frictions, we use a standard measure of financial development: the value of loans to the private sector by banks and other financial intermediaries as a percentage of GDP. This indicator is provided by Beck, Demirgüç-Kunt, and Levine. (2000) and has already been employed in empirical literature concerned with the cyclicality of R&D (see, e.g. Aghion et al., 2010).

Econometric Model

It is well recognized that the Great Recession cannot be considered just a negative phase of the business cycle, since its consequences on macroeconomic performance, especially in the weaker EU areas, lasted well beyond the duration of a normal downturn. Indeed, the 2008 crisis can be viewed as an abnormal amplification of a declining stage of the business cycle, which extended its duration till over the medium-long term. Under this perspective, since a peculiar macroeconomic evolution is recognizable between 1999 and 2014, in which medium term macroeconomic trends follow a cyclical pattern, the empirical investigation of the behaviour of the composition of investment in response to this extended fluctuation must rely upon an estimation strategy capable of isolating short term effects from longer term ones. The Autoregressive Distributed Lag (ARDL) introduced by Pesaran, Shin, and Smith (1999) is a useful and widely adopted approach, since it has several advantages[5]. Firstly, both short and long run parameters can be estimated within the same econometric framework. Secondly, it can be applied even in the case of non-stationary or mutually co-integrated variables (Pesaran and Shin 1999). Finally, long run relationships can be efficiently estimated even in small samples (Ghatak and Siddiki 2001).

Our empirical analysis is based on the estimation of two models. The first one aims at detecting any difference in the composition of investment between pre- and

[4] According to the ESA 2010, the non-manufacturing sectors include: agriculture, forestry, fishing, mining and quarrying, electricity and gas, water supply and waste management, and construction.

[5] Rafferty and Funk (2004) investigate the R&D response to demand fluctuations in the US by using a similar econometric framework based on an Error Correction mechanism specification.

post-crisis periods, taking into account the evolution of macroeconomic conditions and other control variables. In model (1) we estimate the following Error Correction dynamic specification[6]

$$\Delta rds_{it} = \psi_i(rds_{it-1} - \alpha_i gy_{t-1} - \beta_i D_i - \gamma_i Z_{it-1}) + \nu_i \Delta rds_{it-1} + \mu_i \Delta gy_{it-1} + \xi_i \Delta Z_{it-1} + \eta_i + \varepsilon_{it} \quad (1)$$

where rds is the R&D share of total investment, D is a dummy variable – taking value one for years 1999-2007 and zero otherwise – which enters the long run relationship to catch any persistent difference between the pre- and post-crisis period, gy is the growth rate of real GDP to take account of the likely co-movement between the R&D share and the evolution of macroeconomic environment, and Z is a set of explanatory variables including: (a) the government funding of R&D in the business sector, (b) the value of loans to the private sector as a measure of the degree of financial development and (c) a measure of the industrial structure in terms of the ratio between non-manufacturing and manufacturing values added. The parameter ψ measures the speed of adjustment of the error correction process and in order to ensure reversion to a stationary equilibrium relationship it must be significantly negative. The coefficients of differenced variables capture short run dynamics and η_i control for country specific fixed effects.

In model (2) we investigate more deeply the striking of the crisis on the R&D share, by interacting the set of explanatory variables with the crisis dummy

$$\Delta rds_{it} = \psi_i(rds_{it-1} - \alpha_i gy_{t-1} - (a_i + b_i Z_{it-1})D_i - \gamma_i Z_{it-1}) + \nu_i \Delta rds_{it-1} + \mu_i \Delta gy_{it-1} + \xi_i \Delta Z_{it-1} + \eta_i + \varepsilon_{it} \quad (2)$$

This empirical model allows to highlight the relationship between R&D share, financial markets, industrial structure and public policy in the periods before and after the crisis[7]. In model (2) the interpretation of coefficients is completely different from the one in

[6] The lag structure is limited to one due to the time dimension of our panel. It is worth noticing that the Pooled Mean Group estimator used in our analysis has been shown to be robust to the choice of lag order (Pesaran, Shin, and Smith 1999, Martinez-Zarzoso and Bengochea-Morancho 2004). Thus, any concern about the ARDL lag structure is greatly diminished.

[7] Notice that we do not to interact the dummy with GDP growth, since we still want to observe the dynamics of the R&D share in response to the cyclical evolution of the macroeconomic scenario over the medium term.

model (1) and adds meaningful insights to the empirical analysis. Indeed, when D equals to one, in the 1999-2007 period, the long run relation in model (2) is $(rds_{it-1} - \alpha_i gy_{t-1} - a_i - (b_i + c_i)Z_{it-1})$, so that the sum of coefficients $(b_i + c_i)$ measures the effect of Z on the R&D share before the crisis. As the dummy is zero, in 2008-2014, the long run relation reduces to $(rds_{it-1} - \alpha_i gy_{t-1} - c_i Z_{it-1})$. Thus, the coefficients of the non-interacted variables capture the effect of Z on rds in the post-crisis period. Finally, model (1) and (2) are interrelated, since the β coefficient in model (1) is actually specified as $(a_i + b_i Z_{it-1})$ in model (2). This implies that coefficients a and b – i.e. the coefficients of the interacted variables – capture to what extent credit market, industrial structure and government funding explain the change in the R&D share in the period after the crisis, estimated in model (1).

Models (1) and (2) are estimated by using two different estimators: the Mean Group (MG) estimator of Pesaran and Smith (1995), and the Pooled Mean Group (PMG) estimator proposed by Pesaran, Shin, and Smith (1999). Consistent estimates are provided by both estimators despite possible endogeneity, because lags of the dependent and independent variables are included (Pesaran, Shin, and Smith, 1999). In the MG estimation, the model is fitted separately for each country and the mean of short and long run coefficients is consistently estimated by simply averaging on a country basis. Therefore, no cross-country restrictions are imposed by the MG estimator, while the PMG estimator combines both pooling and averaging. In this latter case short run coefficients, speed of adjustment and intercepts may differ across countries, whereas long run coefficients are restricted to be equal across countries. The Hausman test is used to choose between the two estimators. The test compares the MG estimator, which is consistent under both the null and the alternative hypothesis, with the PMG estimator, which is efficient and consistent under the null hypothesis, but inconsistent otherwise. If the Hausman test fails to reject the null hypothesis, then the efficient PMG estimator is selected. If the null hypothesis is rejected, it signals that MG and PMG produce different estimations. In this case, since the efficient estimator is doubtful, the consistent estimator (MG) is preferred.

III. Results

The estimation results are reported in Table 1 for samples EU24, Core, Periphery and Eastern. For each set of countries the first column contains the estimates of model (1), while the second one those of model (2). In the first rows we report the estimator employed according to the Hausman test, below the estimated coefficients of the long run relationship are presented, while the final part of the table reports the short run dynamics.

Table 1. Estimation results of model (1) and model (2)

	EU24		**CORE**		**PERIPHERY**		**EASTERN**	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Estimator	**MG**	**PMG**	**PMG**	**PMG**	**PMG**	**MG**	**MG**	**PMG**
Hausman	22.29	.000	7.79	.010	4.13	23.50	18.65	0.40
p-value	*.0005*	*1.000*	*.1684*	*.1.000*	*.531*	*.0027*	*.0029*	*1.000*
Error Correction	-833***	-.207***	-.216***	-.328***	-.282	-1.216*	-.953***	-.250**
	(.1344)	*(.0593)*	*(.0613)*	*(.1115)*	*(.2885)*	*(.7485)*	*(.2429)*	*(.1291)*
GDPgrowth	-.111***	-.073**	-.438***	-.094**	-.010	-.0080	-.035	.104***
	(.0404)	*(.0309)*	*(.0879)*	*(.0412)*	*(.0168)*	*(.0386)*	*(.0365)*	*(.0160)*
CrisisDummy, *D*	-.0038*	-.0033***	-.021***	-.0028**	-.0031*	-.0011	-.0066***	-.019***
	(.0020)	*(.0010)*	*(.0669)*	*(.0011)*	*(.0114)*	*(.0020)*	*(.0022)*	*(.0033)*
Gvt-funding	.078*	.065***	.225***	.117***	.121***	.090**	.108	.018
	(.0438)	*(.0097)*	*(.0669)*	*(.0397)*	*(.0114)*	*(.0411)*	*(.0810)*	*(.0185)*
*D*_ Gvt-funding		-.051***		-.064***		.068		-.0045
		(.0121)		*(.0214)*		*(.0934)*		*(.0192)*
Financial-Dev	.010	.021***	.0014	.021***	.0081***	.029*	-.012	.051***
	(.0134)	*(.0026)*	*(.0084)*	*(.0030)*	*(.0019)*	*(.0165)*	*(.0085)*	*(.0100)*
*D*_ Financial-Dev		.0004		.0037		-.022		-.052***
		(.0025)		*(.0039)*		*(.0213)*		*(.0084)*
Ind-structure	-.038*	-.061***	-.066***	-.065***	-.061***	-.055**	-.050**	-.041***
	(.0232)	*(.0061)*	*(.0194)*	*(.0069)*	*(.0052)*	*(.0234)*	*(.0197)*	*(.0065)*
*D*_ Ind-structure		-.018***		-.023***		.024		.030***
		(.0055)		*(.0075)*		*(.0314)*		*(.0052)*
ΔGDPgrowth	-.045***	-.022***	-.078***	-.036*	-.0002	-.022	-.023	-.0018
	(.0158)	*(.0081)*	*(.0253)*	*(.0192)*	*(.0129)*	*(.0375)*	*(.0154)*	*(.0105)*
Δ Gvt-funding	.0170	-.011	-.0012	-.025*	.014	.082	.029	-.0053
	(.0205)	*(.0104)*	*(.0224)*	*(.0155)*	*(.0290)*	*(.0737)*	*(.0261)*	*(.0135)*
Δ Financial-Dev	-.0220	.0086	-.0051	.017	.0058	.010	-.028**	-.011
	(.0141)	*(.0061)*	*(.0069)*	*(.0132)*	*(.0060)*	*(.0262)*	*(.0126)*	*(.0072)*
Δ Ind-structure	-.022***	-.016**	-.036**	-.020	-.010	-.091	-.0046	-.012
	(.0080)	*(.0064)*	*(.0153)*	*(.0173)*	*(.0090)*	*(.0610)*	*(.0138)*	*(.0092)*

Note: MG: Mean Group; PMG: Pooled Mean Group. Standard Errors in brackets: * significant at 10%, ** significant at 5%, *** significant at 1%

The Hausman test indicates that PMG estimator provides efficient estimates in both models only in Core sample. Since PMG estimator relies on the existence of a stationary relation among variables that is uniform across countries, while MG estimator averages among country specific estimates, the estimator chosen via the Hausman test provides a first indication of the homogeneity/heterogeneity within groups of countries.

In EU24 sample both estimates display a significant stationary relation. In particular, in MG estimation of model (1) the dummy coefficient shows that on average the crisis impacted weakly on the R&D share, with a modest increase after 2008, only ten percent significant. Overall, the dynamics of the R&D share is mainly driven by the evolution of GDP growth with a negative sign. For a clear understanding of the estimation of model (2), we recall that the sum of coefficients of one variable with its dummy interaction measures the effect of that variable on the R&D share in the pre-crisis period, while the effect in the post-crisis period is captured by the coefficient of the non-interacted variable. The relative size of non-manufacturing sector displays a stronger negative effect in the pre-crisis period, while in both pre- and post-crisis periods lower credit frictions significantly correlates with a higher R&D share. A remarkable difference between subperiods arises with respect to public financing of R&D, with a noticeably higher sensitivity of the R&D share to government incentives in the post-crisis period. Notice that the coefficients of the interacted variables show to what extent each variable may help to explain the change in the R&D share in the post-crisis period. It turns out that, only public funding and the industrial base correlate with a composition of investment more oriented towards innovation in the period following the crisis.

This picture drastically changes, once the analysis focuses on different groups of countries. In the Core sample, the selection of PMG estimator in model (1) reveals a common tendency of the R&D share to move countercyclically in response to the evolution of medium term growth and a common reaction to the crisis in terms of a

significant increase of the R&D share. Looking at the other explicative variables, the coefficient on private credit exhibits a positive sign, but it is not significant. A significant positive effect arises from public support, while the ratio between non-manufacturing and manufacturing sectors impacts negatively on the R&D share. The common frame determining the R&D share does not appear to be disarranged by the impact of the crisis. Indeed, the choice of the PMG estimator in model (2) suggests that a common relation linking the R&D share to financial, industrial and policy factors shaped the dynamics of the composition of investment before and after the crisis. In particular, the degree of financial development exerted a positive effect on the R&D share, without any significant difference between pre- and post-crisis periods. The composition of industrial output had a slightly stronger influence on innovation in the pre-crisis period, while a relevant difference emerges between the coefficients of government funding. Overall, public support to R&D stimulates private innovation, but with a much stronger effect in the post-crisis period. Finally, the coefficients of the interacted variables suggest that the hike in the R&D share after the crisis has been prompted by government policies in support to innovation and by the industrial base.

In the Periphery the PMG estimator in model (1) seemingly supports the existence of a uniform pattern governing the evolution of the R&D share in this area. However, the poor significance of the speed of convergence signals a weak reversion mechanism in the long run. Moreover, the coefficient on GDP growth is negative, but not significant, and the crisis dummy shows a negative sign, only ten percent significant. Altogether, these results suggest that in the Periphery the weak tendency of the composition of investment to react countercyclically to persistent changes in the macroeconomic environment resulted in a negligible reaction of the R&D share to the crisis. The response of the R&D share to government funding and to the industrial structure is significant, and, differently from the Core, the R&D share seemingly appears responsive to the evolution of financial markets. Turning to model (2), the selection of the MG estimator highlights that the crisis had a disarranging effect among Periphery countries. Public funding and industrial structure significantly correlate with the composition of investment, with no significant difference in their effects on the R&D share before and after the crisis. According to a Wald test, the sum of interacted

and non-interacted coefficients of private credit is statistically not different from zero. This implies that no significant effect of financial markets on R&D share emerges in the period before the crisis, while in the post-crisis period just a weak positive correlation is detected. Finally, consistently with the limited reaction of the R&D share in the post-crisis period, the coefficients of the interacted terms are not significant.

In the Eastern sample, the choice of the MG estimator in model (1) indicates that the significant (but small in size) increase in the R&D share in the post-crisis period, accompanied by no tendency of the R&D share to co-move with the evolution of GDP growth, cannot be considered a common pattern among Eastern countries. Government funding and financial markets have no significant effect on R&D share, while a significant negative correlation emerges with the industrial structure. In model (2) the selection of the PMG estimator suggests that, despite the heterogeneity detected by model (1), the crisis activated a common reaction among Central and Eastern countries. With regard to model (2), a remarkable difference emerges between pre- and post-crisis periods. The industrial structure is the only significant variable before the crisis[8]. In the post-crisis period it strengthens its influence on the composition of investment, while financial markets affect positively the R&D share and no effect comes again from public support to innovation. Overall, as for the influence of credit market and industrial base, the results suggest that the Eastern area moved closer to Western EU countries after 2008. As far as the coefficients of the interacted variables are concerned, the negative coefficient of credit markets may help to explain the increase of the R&D share after the crisis, while the positive sign on the interacted industrial structure operates in the opposite direction. Finally, it is worth noticing that in model (2) a marked procyclicality of the R&D share emerges, in contrast with the significant countercyclicality in the Core and the acyclical pattern of the Periphery.

[8] According to a Wald test, the sum of the coefficients of the interacted and non-interacted credit variable is actually not different from zero.

IV. Discussion

The general picture emerging from our empirical investigation depicts a fractionated European area, in which Core, Periphery and Eastern are characterized by different patterns of the R&D share of investment and different degrees of homogeneity. Our interpretation of the results suggests that inside the Core the responsiveness of R&D share to the crisis is consistent with a Schumpeterian mechanism, such that the modified opportunity costs between investment in production capacity and knowledge, sustained the incentive to enhance the innovation component of overall investment. Both Periphery and Eastern samples, albeit for likely different reasons, do not appear to be endowed with such a countercyclical capacity of reaction. In the Eastern the response of the R&D share to the crisis seems consistent with a temporary break in the headway of profound economic, financial and industrial changes, accompanying the catching up process at work in this area since the early 2000s. Differently, in the Periphery the lack of a significant reaction of the R&D share appears rooted in the structural weakness of the overall innovation capacity inside this area. This evidence is telling, since over the medium term the composition of investment influences the dynamics of potential growth. Therefore, the observed dissimilar response of the composition of private investment, especially between Core and Periphery, may represent the premise for macroeconomic divergence, fiscal instability and an overall loss of social and territorial cohesion.

The role of credit markets appears diversified inside the EU area, with particular reference to the dualism Core-Periphery. Inside the Core the credit contraction in 2008 seems to have impacted only as a temporary break in the positive relation linking the composition of investment to the availability of external funding. Credit markets appears to have provided the tools to make innovation spending less volatile than capital investment[9], thus determining a countercyclical dynamics of the composition of investment. A completely different picture emerges in the Periphery. The pre-crisis period does not disclose any significant relation between R&D share and credit market, indicating that the expansion of credit that followed the common currency did not

[9] By using a panel of OECD countries, Falk (2006) confirms the high degree of persistence in business sector R&D expenditure.

stimulate innovation activity relatively more than capital investment. Indeed, in Southern area of the EU the financial liberalization of the 2000s caused an expansion of unproductive investment, mainly directed to real estate properties. In this perspective, the lack of a positive link between credit and composition of investment in the pre-crisis period might be related to the crowding out of productivity-enhancing investment caused by the misallocation of finance resources. In the post-crisis just a flimsy positive correlation emerges, signalling that, following the recovery from the banking crash, the burst of the housing bubble may have encouraged, to a limited extent, credit to flow into R&D investment. Overall, the evidence reveals a weak connection between R&D investment and financing through credit markets. This might signal a lower level of financial development and a more pronounced preference for financing R&D expenditure through internal funding. This latter consideration, in particular, may contribute to explain the modest increase a of the R&D share after the crisis and its acyclical pattern, since, if the incentive to innovate tracks the dynamics of demand, then R&D investment tends to follow a procyclical pattern. In the Eastern sample the late EU membership and the primary goal of sustaining the take-off of fast capital accumulation might have partly crowded out R&D finance, which explains the lack of any correlation between R&D share and credit markets before the crisis. However, in the post-crisis period innovation activity appears highly sensitive to the prevailing credit market conditions. On the one side, this result may unveil the appeal of R&D investment inside an area still favoured by sustained growth prospects and therefore attractive for financial markets[10]. On the other side, the fast financial integration prompted by the growing interdependence between this area and the Western side of the EU may lead to a gradual removal of those credit frictions impeding external funding of R&D projects, laying the basis for an effective process of convergence towards the Western side of the EU.

As for the role played by the industrial base, in all EU areas higher shares of non-manufacturing negatively affect the R&D share of investment. However, only in the Core it contributes to explain the change in the composition of investment towards a

[10] Männasoo and Hein (2017), using firm-level data in Central and Eastern European countries, show that, in terms of loan applications accepted, R&D companies enjoyed an easier access to credit in the post-crisis period.

higher share of R&D in the post-crisis period. As pointed out by the EU Commission report *EU Structural Change 2015*, there is evidence that the recession accelerated the restructuring of the EU economy away from low-productivity sectors. Therefore, the increase in the R&D share detected in the Core after the crisis might have been encouraged by the cleansing-out effect of the crisis on those industrial segments less inclined to seize the "virtue of bad times". This filtering property of the industrial structure is missing both in Periphery and Eastern samples. Even though in the Periphery innovation is sensitive to the relative weight of manufacturing, the shake of industrial base due to the crisis did not influence the response of the R&D share. Inside the Eastern the stronger correlation between industrial structure and R&D share in the post-crisis period reveals that the accumulation process has been accompanied by a slow transformation of the industrial base towards manufacturing[11]. However, our estimation results show that the industrial structure prompted a procyclical reaction of the R&D share after 2008. Sapir (2014) notices that the catching-up process continued, though at a modest pace, between 2008 and 2012; therefore, a plausible explanation of this specific pattern is that, in the aftermath of the crisis, the upswing of investment to foster capital accumulation has, to some extent, delayed the recovery of R&D investment.

The role of public R&D policy in the years straddling the crisis has been investigated by several papers (Makkonen, 2013; Iskak and Radošević, 2017; Pellens *et al*., 2018). These contributions highlight that the crisis impacted heavily on government R&D budgets, but with striking differences within the EU area. The overall picture is that, in the Northern part of the EU innovation policies followed, on the whole, a countercyclical pattern, in Southern EU the crisis led to an overall breakdown of national R&D budget, while in Central and Eastern countries, despite a mixed evidence, it appears that the heavy impact of the crisis has been compensated by a stronger flow of EU funds[12]. Our results are in line with the above literature and offer few additional insights. It neatly appears a pattern in which government incentives become less effective moving from Core to Periphery. In both areas government

[11] This is process of industrial transformation is confirmed by the *EU Structural Change 2015* report (European Commission, 2015).
[12] This general picture is also confirmed by Izsak et al (2013).

funding of R&D projects stimulates innovation in the business sector, but, while in the Periphery the sensitivity of private innovation to public funding does not show any difference between pre- and post-crisis periods, inside the Core it markedly magnifies after the crisis, indicating that in this area the public stimulus to private expenditure in innovation may actually be stronger over downturns. Indeed, in a policy perspective this evidence is particularly interesting, since it suggests that in the presence of endogenous mechanisms able to preserve a smooth path of R&D investment, an active countercyclical policy in support of innovation may display significant multiplicative effects, with positive short run effects on demand and positive supply effects in the medium term[13]. Finally, considering the Central and Eastern EU area, the lack of a significant link between government funding and private R&D might reflect a compelling dynamics of capital accumulation. In a catching-up environment governments may have a stronger incentive to sustain and preserve the process of economic development through tangible and intangible infrastructure. Therefore, national budgets devoted to R&D support may be parsimonious compared to more advanced economies and more vulnerable to external shocks. As pointed out by Iskak and Radošević (2017), the hit of crisis further constrained R&D budgets because of the need to implement redistributive policies and led to a dissimilar reaction of public R&D designs, but, in general, the use of EU structural funds allowed a substantial maintenance of the portfolio of R&D measures in the Central and Eastern area.

On the whole, in the Core the policy design outlined in Europe 2020 fits well with the relation linking the R&D share of investment to credit market, industrial base and government support to R&D and appears a suitable frame to stimulate innovation towards the targeted objectives, especially if implemented in a countercyclical perspective. As for Central and Eastern countries, the sensitivity of the composition of investment to the prevailing credit conditions and to the industrial base, which emerges

[13] Brautzsch et al. (2015) investigate the macroeconomic effects of R&D subsidies undertaken by the German government in 2008. Consistently with our results, the authors find that R&D subsidization did not have crowding-out effects on private R&D investment, but stimulated additional spending. Moreover, they show that this policy measure had a multiplicative effect on output, value added and employment that was twice the initial funding. For a theoretical discussion of the complementarity between governmental R&D and private R&D see Leyden and Link (1991).

in the post-crisis period, suggests that an active industrial policy and measures aimed at improving the access to financial markets may effectively encourage innovation and speed up the process of accumulation. However, since public support still appears poorly effective, the reliance on European funds appears essential to promote the desired levels of innovation. In the Periphery the limited reaction of the composition of investment over the crisis and the weak connection between R&D share of investment and financial market are overall indicative of a difficult relationship between finance and business. Indeed, this does not seem to depend on the actual development of the financial and industrial systems, but more likely on a conservative entrepreneurship, that constraints the flow of new ideas to be turned into products and services. In this perspective the implementation of the policy design outlined in Europe 2020 appears challenging and the role of public support to innovation emerges as a necessary path to start bridging the innovation gap between this area and the Core.

Finally, with reference to Europe 2020 objectives, the heterogeneity inside the EU – neatly revealed by the medium term cyclicality of the R&D share and by the reaction of the composition of investment in the period following the crisis – raises a further issue. In the Core the crisis appears to have brought into focus this countercyclical capacity, highlighting how the enhanced sensitivity of private R&D expenditure to public funding and the industrial base reaction to the new environment contributed to a composition of investment more oriented towards innovation in the period after the crisis. Both Periphery and Eastern samples, albeit for likely different reasons, do not appear to be endowed with such a countercyclical device. The lack of a homogenous countercyclical dynamics of the composition of investment contributes to make the Europe 2020 convergence expectations vulnerable to severe and long lasting downturns. In case of a general economic decline, a misallocation of productivity-enhancing investment in some EU areas may amplify the persistence of the recession, reinforcing the pro-cyclical pattern of innovation, which further amplifies the persistence of the recession. This progressive weakening of an endogenous mechanism able to restart a path of growth, may, in turn, start diverging trends in macroeconomic performance.

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