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Abstract:
A recent literature has pointed at potential negative effects of exchange rate volatility on innovation. In this paper, we propose that there may be a direct effect as well as an indirect effect via export activity. We test these hypotheses for sectoral R&D intensities using OECD panel data for manufacturing and services sectors for 14 OECD economies and the years 1987 - 2003. We find that the direct negative effect of volatility is pronounced in manufacturing sector but is dominated by the indirect effect via the export channel. Services do not face any effects of volatility on R&D intensities. While it is not clear which channel dominates our results confirm that there is a negative volatility affect related to openness on a sectoral level.

Keywords: E32, F31, O32

JEL classification: R&D intensity, Innovation, Real Exchange Rate, Volatility, Exports, OECD-Countries

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1. Introduction[1]

Traditionally, macroeconomic stability and economic growth have been treated in separate strands of the literature. However, recently, a literature on growth and cycles has evolved which considers long-run effects of macroeconomic volatility on growth (see, e.g., Loayza et al. 2007). The volatility of the real exchange rate plays an important role in a range of models arguing that productivity depends on learning-from-exporting (see, e.g., Prati and Tressel 2008; Stokke 2008). Driving by external shocks such as fluctuations in capital inflows or terms-of-trade changes, temporary structural adjustment due to real exchange rate fluctuations has lasting effects on the level of productivity. While in this case macroeconomic volatility impacts on innovation via exports, other papers assume a more direct impact of volatility on innovation and growth (e.g., Aghion et al. 2006). In these endogenous growth models, real exchange rate uncertainty reduces the level of innovative activities assuming that this negative effect might be mitigated by a well developed capital market which allows for hedging these risks.

It is quite evident that, given the current turmoil in the world economy, the potential long-run effects of an increasing expectation of macroeconomic volatility and, more specifically, also real exchange rate volatility is a timely topic. So far, empirical evidence is rather eclectic. Aghion et al. (2006) test only the relationship between real exchange rate volatility and growth treating the transmission via innovative activities as a black box. Generally, empirical work on the determinants of innovative behaviour so far has been based on panel data for individual countries. This data showed that there is a correlation between exports and R&D but had to neglect an impact of macroeconomic volatility on innovation. Hence, a test for a direct impact of real exchange rate volatility on innovative activity still stands out.[2]

Compiling panel data on exports, exchange rates and R&D expenditures of 14 OECD countries, this study analyzes the impact of macroeconomic volatility on R&D in manufacturing and services sectors. We propose that exchange rate volatility displays direct as well as indirect effects on R&D expenditure. We find that the direct negative effect of volatility is pronounced in manufacturing but not in service sectors. In addition, manufacturing sectors are affected by both a direct effect of

[1] The authors like to thank Michaela Rank for editorial and technical support.

[2] A recent paper by Becker and Hall (2009) reveals a significant impact of exchange rate uncertainty on foreign direct investment in R&D for the UK based on a panel of manufacturing industries. Other papers are, e.g., Miller and Reuer (1998) and Zeitz and Fayissa (1994).

volatility on innovative activity as well as by an indirect effect of volatility via its negative effect on exports.

The next section briefly deals with the relevant literature and the possible channels of the transmission of the exchange rates. The third section briefly highlights the various data and methodological aspects of how this exchange rate uncertainty has been captured and gives a brief account of our empirical methodology. The fourth section presents the estimation results and the fifth section concludes.

2. Exchange Rate Volatility, Innovation, and Exports

A strand of the literature has evolved which points to the impact of macroeconomic volatility on growth via innovative activities. Important contributions to the literature can be organized according to the channels through which volatility affects growth.[3]

First, volatility affects investment. Simple one-sector AK models, as discussed by Mendoza (1997) and Jones and Nanueli (2005), with stochastic productivity and CES utility relate the effect of volatility on growth to the relative weight the representative consumer assigns to the income or substitution effect. Both papers show that when individuals have a sufficiently high coefficient of relative risk aversion, increased volatility will raise growth, and vice versa. In AK models with stochastic technologies in several sectors the impact on volatility on growth can be shown to depend on a set of parameters. Barlevy (2004) considers an AK model in which adjustment costs cause the investment function to be concave. He demonstrates that volatility lowers growth through the volatility of investment even for a constant volume of investment, whenever the investment function is strictly concave. Because of diminishing returns to investment, the positive effect of above average investment is smaller than the negative effect of below average investment. A similar mechanism is at work in Aghion et al. (2006).

Alternative models of the influence of volatility on growth are based on human capital accumulation. Martin and Rogers (1997) present a model in which human capital is accumulated through learning by doing. Workers fail to internalize fully the positive externality of learning by doing on future wages. Therefore, their labor supply is inefficiently low and policies eliminating volatility can raise growth rates. Positive effects of fluctuations can emerge when, instead of being complementary to production activities, human capital accumulation is a substitute as in Aghion and Saint-Paul (1998).

Second, volatility may affect research expenditure. In a recent contribution Aghion et al (2006) model the effect of exchange rate volatility in a small open economy. Assuming that credit is needed to overcome liquidity shocks which otherwise impede innovative activity implies that the probability of innovation is a linear function of the real exchange rate. As long as this probability is strictly

[3] See, Drautzburg (2008) for an overview.

concave in its arguments, the same mechanism employed in Barlevy (2004) ensures that lower volatility raises the expected growth rate via an increase in innovative activities. The empirical estimates show that there is actually a negative relationship between real exchange rate volatility and growth. However, the innovation channel is not estimated explicitly and the transmission from volatility to growth is treated as a black box. As discussed above, higher growth rates may be due to a positive investment effect of lower real exchange rate volatility. In addition, it is plausible to assume that real exchange rate effects on investment and innovation depend on the openness of an economy because different degrees of openness and hence, relative weight of traded to non-traded goods produced in an economy implies different sensitivity to real exchange rate shocks.

Moreover, exchange rate volatility and, therefore, uncertainty of exchange rate changes also affect economic growth via the trade channel. With increased competition among firms operating in monopolistic markets across countries, the uncertainty of exchange rates drives a wedge between the values of revenues earned by firms located in different markets (Krupp and Davidson, 1996). Hence, in the short run, stability of exchange rates is crucial to export oriented firms as they affect their profitability. Fluctuations in the exchange rates impact on the export oriented firms' real decisions in three ways.

Firstly, depreciation in the real exchange rate would boost the exports of firms by making them more competitive and thus increasing their total export revenue. This would further lead to a fall in the demand for all inputs including capital. This is termed as the revenue channel effect (Campa and Goldberg 1999; Nucci and Pozzolo 2001). They also have shown that such an effect increases with the elasticity of demand for firm's products by raising the pass-through effect of exchange rate uncertainty onto the prices of imported inputs by the firm. This is one of the most commonly noticed phenomena or the apparent consequence of exchange rate uncertainty on the firms.

Secondly, depreciation in the real exchange rate would impact upon the cost of imported goods by increasing the costs. So, the effect of an appreciation of real exchange rate would work in the opposite way by reducing the cost of imported inputs. This is particularly relevant among most of the firms across the world as they are net importers of technology with the exception of American and German firms. This effect was also shown previously by Campa and Goldberg (1999) and Nucci and Pozzolo (2001) in their works. However, in this context some studies have shown that particularly for firms operations across countries, exchange rate uncertainty might positively affect their decisions on location of production plants if they can operate under decreasing cost curves.

Finally, even the level of demand for labour in export oriented firms would be influenced by fluctuations in the real exchange rate in the short run. It works out in the following manner. Depreciation in the real exchange rate reduces the demand for labour for those firms that are heavily dependent on imported inputs. This effect again arise through fluctuations in firm's output and import costs (Campa and Goldberg 2001; Galindo et al. 2006), thus leading to adequate amount of substitution between labour and capital for production processes.

In this regard, several other authors have investigated the impact of exchange rate uncertainty on firm level decisions. (Dixit and Pindyck 1994), (Darby et. al, 1999)) have modelled the influence of exchange rate uncertainty on firm investment by looking at the option based approach. Other works like (Baum et. al, 2000) have looked at the effect of exchange rate volatility from a viewpoint of macroeconomic uncertainty. Interest rate uncertainty also plays important role in influencing firm profitability. But, they have adopted a signalling approach to model the volatility in spot exchange rates.

Hence, both innovation and export activity has to be assumed to be determined by exchange rate volatility. At the same time, innovation and exports influence each other as pointed out by Lachenmaier and Wößmann (2006). Endogenous growth models recognize open-economy effects by endogenizing the rate of innovation and predicting dynamic effects of international trade on innovative activity. Models featuring such effects include contributions by Grossman and Helpman (1991), Segerstrom et al. (1990), Young (1991), and Aghion and Howitt (2006). Two channels can be distinguished in such models that affect innovative activities of exporting firms. First, the fiercer competition on international markets forces exporting firms to improve their products and processes to remain competitive, thus increasing their probability of innovation. Second, exporting firms may learn by exporting in that they gain access to technical expertise from their buyers on foreign markets which non-exporting firms do not have.

Building on a different stand of trade theories, Grima et al. (2008) and Tintelnot (2008) show that innovation in abatement technologies depend on the export status of firms. Building on the trade model with heterogeneous firms (Melitz 2003), it can be shown that more productive exporting firms opt for green technologies because they can afford them. This effect is sustained through a widening productivity gap between exporters and non-exporters. This is because green technologies, being invariably newer, more advanced technologies, often involve the replacement of obsolete or poorly performing equipment with state of the art equipment. This additional effect means that the introduction of green technology by exporters can bring about further productivity improvements in addition to combating environmental fallout. At the same time, more traditional trade models stressing product cycles like in Vernon (1966), Krugman (1979), and Dollar (1986) assume that developed countries export innovative goods and have to keep up their exports by continuous innovation. Hence, the more they innovate the larger are their exports. Hence, the potential endogeneity of innovation and trade raises a severe problem for empirical tests of the prediction that trade increases innovative activities.

All in all, the brief discussion of relevant strands of the literature leads to the following working hypotheses which are to be tested in the following sections:

- Innovative activity depends on openness and, more specifically, on the export performance of an economy or the export orientation of a sector *and* vice versa; the higher export intensity the higher is innovation activity.
- Innovation as well as export performance depends on macroeconomic volatility as measured by the real exchange rate; the lower real exchange rate volatility, the higher innovation and export activity.

Hence, empirical tests of the determinants of innovative activity including export performance and real exchange rate volatility have to recognize potential endogeneity problems linking innovation and export as well as the fact that both innovation and exports may be affected by macroeconomic volatility.

3. Data and Empirical Methodology

Data for monthly real effective exchange rates which are necessary in order to construct an annualized measure of exchange rate volatility are taken from the International Financial Statistics (IFS) database. OECD Structural Analysis Statistics (STAN) is primarily a collection of national accounts and industrial survey data from 26 OECD countries. The annual data on innovation and sector characteristics was collected from a sub-database of STAN called the STAN-indicators database which includes information on the Business and Enterprise Research and Development Statistics (BERD) for all OECD countries. Usable data for all countries is available mainly from 1987 and therefore we restrict our analysis to the time-period 1987-2003. An advantage by restricting to this time period is that, it is expected to account for most of the recent financial crises or booms. Out of the 26 countries, not all of them provided data on business R&D and some of them had many missing observations. After removing such countries from the dataset, we arrive at a sample of 18 countries for the time-span 1987-2003. After accounting for the variables needed for empirical analysis, the sample size reduces to 14 countries.

3.1 Measuring Exchange Rate Volatility

Most of the studies dealing with exchange rate volatility have attempted to indicate some kind of medium to long run phenomenon. Several authors have resorted to the simple time series measures like the standard deviation of the annualized exchange rates or the deviation from the trend of the real exchange rates. In this regard, Darby et al. (1999) have considered the latter approach by applying the Hodrick Prescott filter to the logarithm of real effective exchange rate to generate a measure of volatility. Maquering and Verbeek (2000) have shown that volatility in time series data tends to appear in clusters, with periods of high volatility followed by periods of low volatility. Such phenomenon indicates persistence in volatility and the variance of such a time series is not constant over time. Therefore, we resort to the GARCH approach to measure exchange rate volatility due to two reasons:

firstly, to capture persistence in the exchange rate data and secondly, due to the fact that conditional variance approach uses more available information than the simple standard deviation method to generate the volatility measure. The first insight into this concept was presented by Bollerslev (1986), who modeled the exchange rate as a generalized autoregressive process conditional on normally distributed mean and variance of the series.[4]

Bollerslev (1986) generalized the ARCH methodology introduced by Engle (1982) which takes the form of GARCH (p, q) model as[5]

$$y_t = \lambda_0 + \sum_{i=1}^{k} \lambda_1 y_{t-1} + \varepsilon_t \tag{1}$$

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_i \sigma_{t-j}^2 \tag{2}$$

Equation (1) is the mean equation and it is followed by the conditional variance equation in (2). The conditional variance equation gives us a one period ahead forecast based on the past information with ε_t being serially uncorrelated with zero mean, and the conditional variance being σ_t, that changes through time. α is the coefficient of the lag of the squared residuals from the mean equation, is the ARCH parameter. This gives us the news about volatility from the previous period. The volatility clustering is shown by the size and significance of α. β is the GARCH parameter and α + β measures the persistence of volatility. Any shock to volatility is permanent if α + β = 1. Volatility is explosive if α + β > 1. A shock to volatility in one period will lead to even greater volatility in the next period. For a well defined GARCH (p, q) model, all the parameters in the autoregressive process must be non-negative and the roots of the polynomial lie outside the unit circle. That is,

$$\alpha_i > 0 \text{ and } \beta_i > 0 \tag{3}$$

It follows from equation (2) that ε_t is covariance stationary if and only if $\alpha_i + \beta_i < 1$. In our case study, we employ a first order GARCH (1, 1) model and hence would require

$$\alpha_1 > 0 \text{ and } \beta_1 > 0,$$

with

$$\alpha_1 + \beta_1 < 1 \tag{4}$$

[4] Alternatively, structural models are proposed, e.g., by Krugman (1998) based on the argument that exchange rate volatility could be influenced by swings in real business cycles among different trading economies. In this case, uncertainty in exchange rates and productivity shocks influence firm profitability.
[5] Several other authors that have modeled volatility or uncertainty using GARCH models are (Huizinga 1993, Price 1995 and Serven 2002).

Bollerslev, (1986) has noted the fact that most of the volatility can be captured by GARCH (1, 1) models and one need not necessarily resort to higher order autoregressive processes. General understanding on the estimates of the volatility measure are that if the sum of the coefficients of the variance equation are greater than 1, it implies high persistence in the volatile nature of the series.

We considered the monthly frequency for estimation purposes with each country having 252 observations. Before proceeding with the GARCH estimation, we ensured that all the REER series were stationary by conducting unit root tests and the series we employed for the GARCH (1, 1) modeling are first differenced. We have also tried the logarithmic transformation of the level variable (REER) but it was not found to be stationary. From our exercise (see Figure 1) we note that a few OECD countries such as Finland, Ireland, Italy, Belgium, Japan and Sweden had experienced high volatility with variance equation parameters greater than unity. And the volatility measure for USA has shown a structural shift over the sample period.

[Insert Figure 1 about here]

3.2 Measuring R&D intensity

Numerous studies have put forward several determinants of innovative activity, mainly on the firm-level. On the sectoral or industry level, however, the determinants of innovative activity have been limited to the analysis of sectoral innovation systems approach and R&D intensity distribution analysis. The sectoral systems approach (Malerba 2002) considers sectoral knowledge base, technologies, inputs and demand characteristics. However, empirically the sectoral systems approach is not suitable for our analysis due to measurement and data availability issues. We concentrate on R&D intensity instead, where extensive research has been focused on distributional regularities within industries (Cohen & Klepper 1992; Lee 2002). An important result of these studies has been that R&D intensity (measured by ratio of R&D expenditure to sales) follows a log-normal distribution and similarities are reported within industries. These regularities themselves indicate an underlying common probabilistic process to all industries and that these regularities are conditioned by the firm size effects within the industries.

Figure 2 presents the R&D intensity distribution across all the manufacturing and services sectors on a pooled dataset of 16 countries in the sample. The measure of R&D intensity that we utilize is based on the production method where R&D intensity is a share of total production represented in percentages. This is similar to Cohen and Klepper (p.774, 1992) who use R&D intensities "because R&D expenditures and sales are highly correlated". Moreover, the benefits of using R&D intensities instead of expenditures include correction for scale factors and also firm and industry regularities that might be seen in production. Cohen and Klepper (1992) show that there are striking regularities in the R&D intensity distributions across different sectors and that there is a common probabilistic process that underlies these distributions.

[Insert Figure 2 about here]

As can be seen in Figure 2 we first compared a pooled structure of R&D intensity comparing total manufacturing and total services in all 14 OECD countries for all years between 1987 and 2007. In contrast to Cohen and Klepper(1992), the log-normal structure is not to be seen. In Figure A1 (see appendix), we expand this to show panel-line plots of R&D intensities which are country and year-wise. While R&D intensity in manufacturing shows a steady increase in most of the countries, especially Sweden and Japan, there is a common pattern to all the countries. The same is not true in the case of services. The patterns seem to show constant behavior for some years and then a jump to the next level. The breaks that can be seen in the figure are due to unavailability of data from the respective countries for some years.

3.3 Control variables - industry size and intermediate inputs

There are two reasons why we considered industry size as a control variable in our analysis to explain variation in R&D intensity. Firstly, industry size (the number of employees) is crucial in knowledge flows within and across industries (Griliches and Lichtenberg 1984). Within each industry the market structure matters for how R&D expenditure is allocated by small and large firms. As Acs and Audretsch (1987) show, large firms and small firms have relative advantages depending on the concentration, capital-intensity and innovative nature of the industries within the sector. While small firms tend to utilize a large proportion of skilled labor, large firms tend to be more capital intensive and invest more in R&D activities.

The second reason why we consider industry size is due to employment effects on innovation. Wolff (1995, 2003) studies skill levels of employees and technological change depending on various measurements of skills such as motoric skills, workplace skills and cognitive skills. On one hand, the studies find that industries vary in their demand for skills and some industries tend to be over-demanding and some are de-skilling. However, specific to R&D intensity, it was found that a substantial change in complexity and interactive skills had positive effects on R&D intensity. More recently, Asker and Baccara (2008) present a theoretical proof that as industry size increases, R&D expenditures become more concentrated.

[Insert Table 1 about here]

As shown in Table 1, industry size in the manufacturing sector decreased between 1987 and 2003 from about 21% to 16%. There seems to be an overall employment shift towards services which showed an increase in the same period from 64% to 72%.[6] Figures A2 and A3 show the industry size

[6] Table 1 shows also that the R&D intensity increased in both manufacturing and services sectors across OECD countries. However, the figures of R&D intensity are quite low. While in 2003 the all manufacturing sectors in 14 countries on an average allocated 2% of their production to R&D and in the services sector it was 0.2%. Export shares in production have increased from 36 to 50% in the manufacturing sector between 1987 and 2003.

distributions for 15 countries in both manufacturing and service sectors for the year 2003. As can be observed, there are pronounced differences between countries. For example, the manufacturing sector distribution is right skewed and the services sector shows a left skewed distribution. Netherlands on the other hand shows a very right skewed distribution which is almost log-normal distribution in both sectors.

The effect of imported intermediate inputs on firm level investment can occur in the following manner. A depreciation of the real exchange rate increases the cost of imported intermediate inputs. The opposite effect can occur following an appreciation. For export oriented firms, while depreciation boosts export revenues in the short run, simultaneous rise in imported input costs following depreciation could hamper investment. Landon and Smith (2007) have concluded in their work that currency appreciations associated with a decrease in the cost of imported inputs are greater than a decrease in the cost of other domestic inputs. However, they state that the impact of the change in price on investment depends on substitutability between imported intermediate inputs and domestic inputs. Similarly, Nucci and Pozzolo (2001) and Campa and Goldberg (1999) have shown that the effect of imported intermediate inputs on firm level investment varies with the firms' monopoly power and the degree of substitutability between imported and domestic inputs. Lower monopoly power in the market results in a greater variation in the price of imported intermediate inputs.

The value of intermediate inputs has significantly increased in both manufacturing and services sectors in OECD countries. As shown in Table 1, the share of intermediate inputs in manufacturing sector has risen by 73% from 1987 to 2003. Whereas, the share of intermediate inputs in services has more than doubled with a rise of 129% from 1987 to 2003. In the presence of exchange rate fluctuations, imported inputs could have a significant impact on investment activity across economies. Recent studies have accounted for imported intermediate inputs as a determinant of firm level investment (Landon and Smith 2007, Nucci and Pozzolo 2001, Campa and Goldberg 1999).

3.4. Volatility, exports and innovation – time and cross-section dimensions

As argued in section 2 of this paper, export activity have to be assumed to impact on innovative activity but, at the same, time may be affected by innovative activity itself. Figure 3 shows how the variables innovation, exports, and volatility related to each other. Looking at the country variation of changes in innovation and export activities over the observation period and the average exchange rate volatility during that period seems to suggest a rather positive relationship between average volatility and change in innovative activities (Figure 3). Countries with high volatility, e.g., Finland, even increased R&D. To the contrary, the relation between exports and volatility seem to be more on the negative side with countries showing high average volatility increased their export intensity more slowly. Overall, the descriptive statistics do not lend strong support for either a direct or an indirect

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We do not have data for services sector in this regard. The export-import ratios seem to have had very minute change from 104% to 108%.

effect of volatility on innovation. Hence, the hypothesis that exchange rate volatility has a direct effect on innovative activity is not supported by the simple correlation shown in Figure 3. At the same time, there are no strong correlations revealed on the other relationships either. Hence, the hypotheses on direct and indirect effects of exchange rate volatility on innovation has to be tested using all the information contained in the panel data.

[Insert Figure 3 about here]

4. Estimation Results

In order to test our hypotheses, we use panel estimation methods and check for applicability of random vs. fixed effects models. The first estimation equation involves testing for direct effect of exchange rate volatility on R&D intensity for both manufacturing and services sectors for 14 OECD countries in the period 1987-2003. The second specification tests our second hypothesis that the effect of volatility is channeled through exports and thus there are indirect effects on R&D intensities. In the second specification we instrument two different measures of export performance, namely, export share in production and export-import ratio by exchange rate volatility and intermediate inputs. We therefore have two major regression specifications (direct and indirect).

Table 2 presents the unbalanced panel random effects regressions[7] for total manufacturing and total services sectors of 14 OECD countries in the period 1987-2003. There are two separate specifications involving the measurement of exports. One is with export share in production and the other is the export-import ratio. At the first glance one can see that exchange rate volatility has a direct negative effect on the R&D intensities only in the manufacturing sector. In the services sector the effect is insignificant. The export share in production shows a positive significant effect in manufacturing while the export-import ratio does not.[8] Traditional variables such as industry size and intermediate inputs affect R&D intensity in OECD service sectors positively. Industry size has no effect on manufacturing R&D intensity but intermediate inputs show a positive effect at a low level of significance.

[Insert Table 2 about here]

Overall, it is important to note that the regression results lend some support to the hypothesis of a negative direct effect of exchange rate volatility on innovative activity in the export sector only while innovation in services seem to be driven by traditional determinants like industry size and intermediate inputs. Especially, the negative volatility affect is robust to fixed effect and pooled estimations as shown in Table A1.[9]

[7] The Hausman test has been applied to show that the random effects model has to be used.
[8] For the service sector, we do not have data on export shares in production as well as export-import ratio.
[9] Dummy variables revealed that on average country level effects on R&D intensities are smaller compared to U.S. and that all other countries have lower R&D intensities. We also accounted for industry level correlations.

In the random effects specification, the explanatory power of within group specification with export shares is higher, however, when export-import ratios are considered, the within-group R-square decreases but the overall group and between group R-squares increase. In this sense, the export-import specification makes better prediction. ON the other hand, for services only the within-group R-squares are higher. The general low level of R-squares might be due to missing many firm level variables for which we could not find aggregated data. However, all the estimations confirm with the Wald test, rejecting the zero coefficient hypothesis.

As argued above, export activity may be endogenous to innovative activity and depend on exchange rate volatility itself. Table 3 and 4 present the results from the instrumental variable random effects panel regression in the manufacturing sector which consider these arguments. In Table 3, we show the results of the first specification where export share in production is explained by exchange rate volatility. While the export share shows as positive significant effect on R&D intensity, the exchange rate volatility affects export shares negatively in the first stage of the two-stage model. Considering the second specification in Table 4, using export-import ratio, one can observe that the effect of volatility via the export-import channel is more pronounced than via the export share channel. However, when looking at the overall (indirect) import of volatility on innovation this is balanced out by the higher coefficient of export share compared to export-import ratio. Hence, both regressions reveal a comparable indirect impact of volatility on innovation.

[Insert Tables 3 and 4 about here]

To sum up, our hypotheses remain true after testing for different specifications. Exchange rate volatility seems to have both direct as well as indirect effects on manufacturing R&D and no impact on R&D in service sectors. Hence, openness and volatility matters for innovative activity. Given the fact that the instrumental variable specification accounts for potential endogeneity problems, results on indirect effects seem to be slightly more convincing so far.

5. Discussion & Conclusion

Our study points at the importance of macroeconomic volatility on innovative activity. By far, the literature dealing with innovation has concentrated on the evolution of industries and channels of innovation, but has largely ignored the export activities and the exchange rate effects on this relationship. To our knowledge, our study is the first to address this gap by directly testing for the impact of macroeconomic volatility on innovative activity. The literature points out at mixed effects in a way that some effects like the "revenue channel effect" predict an increase in export revenue due to

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Significant coefficients point in the same direction than those shown in Table 2. However, a higher level of heterogeneity did not allow for robust estimations. We also tried to consider that countries trade with the other in the sample and have different comparative advantages but we could not account for that due to lack of data. Finally, we wanted to check for robustness of results using the labour market approach by including share of skilled- workers, but the data was unavailable for the given period and countries.

exchange rate depreciation, while at the same time appreciation would decrease the cost of an imported good (this is important if raw materials are imported). We proposed therefore that innovative activity depends on openness and specifically, export performance of an economy or a sector. This relation, in turn depends on the volatility of exchange rates

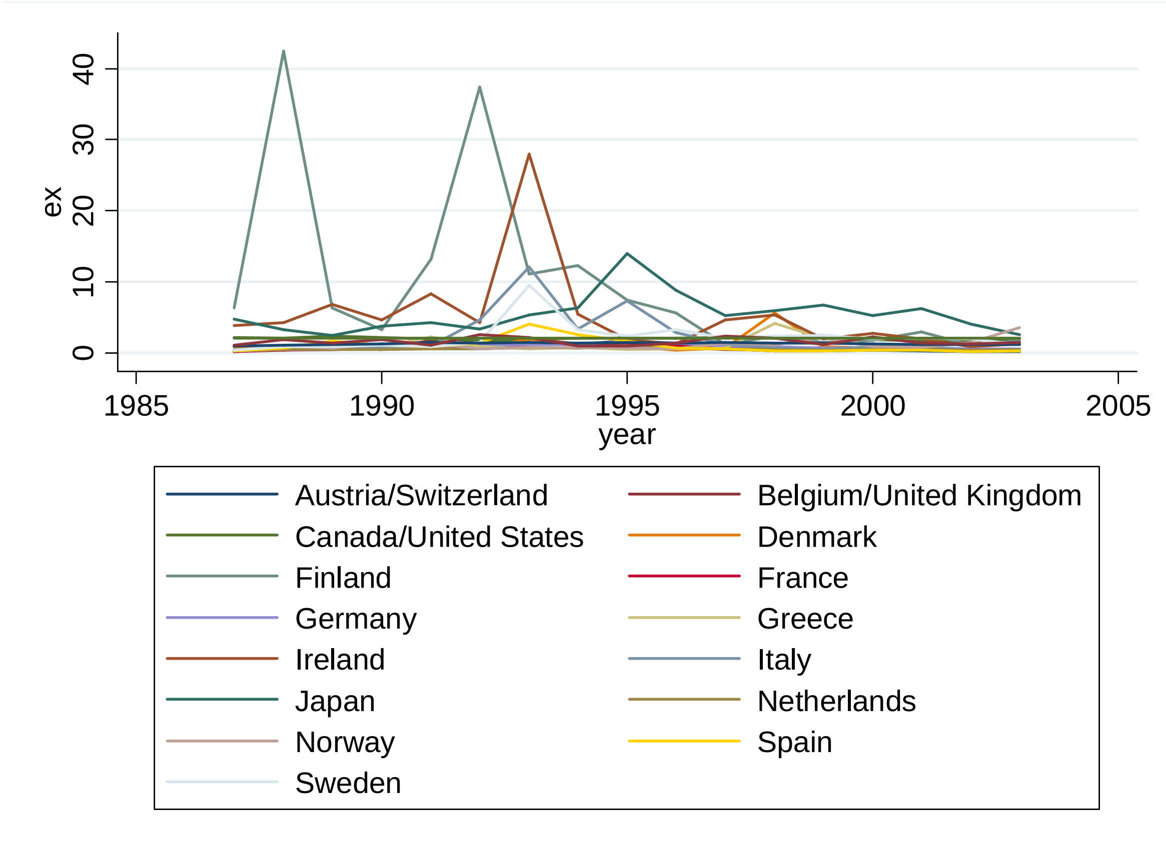
We construct a conditional heterosckedastic measure of the real effective exchange rates (REER) for 14 OECD countries from a GARCH (1, 1) model (Bollerslev, (1986) and test whether this measure of macro volatility influences R&D expenditure on a sectoral level, distinguishing between manufacturing and service sectors. We compiled a panel data on 14 OECD countries and compared manufacturing and services sectors across these countries and tested two specifications namely, one with a direct volatility effect and another with an indirect effect where we instrumented exports with volatility. The results are as follows:

- Real exchange rate volatility indeed negatively affects R&D intensity in the manufacturing but not in the service sector. This result gives a first hint on the importance of export activities because real exchange rate volatility, i.e. the volatility of the relative price of tradeables over non-tradeables should matter for tradable goods sectors as well as for non-tradable goods sectors. In addition, the export share in production is also shown to impact (positively) on R&D intensity.
- For the manufacturing sector, the alternative specification testing the hypothesis about an indirect effect of volatility on innovation confirms the importance of export activities. Considering endogeneity problems, the instrumentation of export activity by real exchange rate volatility (among other variables) reveals a strong indirect effect. Volatility negatively affects export activity and, because of a positive impact of export activity on innovation, also innovation.

To confirm the indirect effects result, we performed additional tests to find that countries that increased their export intensity slowly, encountered severe negative effects of volatility on their R&D intensities. As a robustness check to find if there is a cross-country story, we performed fixed effects estimation to find that the average country effects are smaller on R&D intensities. So, a country-level story might not fit the theory while we considered OECD economies, which might portray similar institutional and developmental features.

All in all, it could not be ruled out that the proposed negative effect of exchange rate volatility on innovation is based on indirect effects via export activity rather than on a direct effect. Hence, the empirical result of Aghion et al. (2006) that volatility negatively affects long-run growth may be based on other transmission channels, e.g. through trade. Clearly, there are significant limitations that require to be addressed with larger datasets and complex methods on both firm and sub-sector levels. Yet, we are able to show that policy efforts which aim at increasing innovative activity must realize that more often when firms do not tend to invest in R&D it might be due to the channels outside the firm's control. Exchange rate volatility is an outcome of many changes in several economies and their sectors of economic activity. Volatility affects revenue streams of sectors and therefore the question arises on how to shield R&D investments from such effects. A higher level of exchange rate stability should benefit R&D investments both directly and indirectly by stabilizing export revenues.

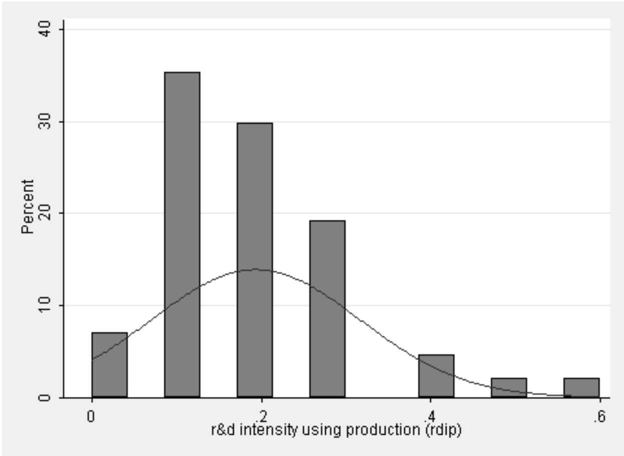
Figure 1 – Conditional Real Exchange Rate Volatility in OECD Countries, 1987 - 2003



Source: Own calculations based on IFS database.

Figure 2 - **R&D intensity using Production method on pooled dataset (manufacturing vs. services)**

Total Manufacturing



Total Services

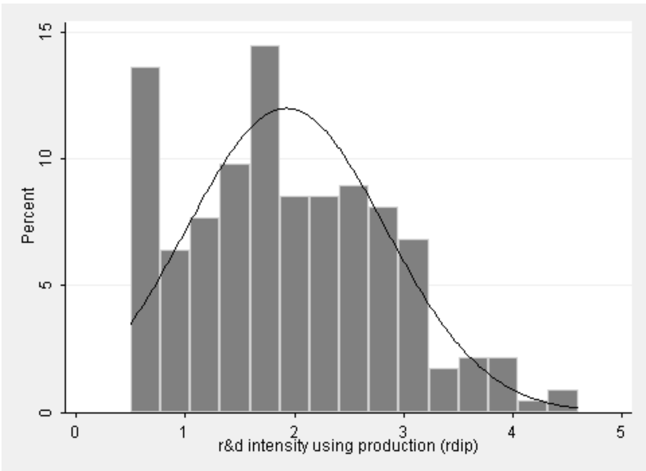


Table 1 - Descriptive Statistics for the Main Variables, 1987 and 2003

Variable	Measurement	Total Manufacturing		Total Services	
		1987	2003	1987	2003
RDIP (R&D investment)	R&D expenditures as a percentage of production	1.8 (0.84)	2.05 (1.09)	0.122 (0.083)	0.20 (0.12)
Export share in production	Exports as a percentage of production	35.50 (17.86)	50.36 (29.87)	n.a	n.a
Export-import ratio	Exports as a percentage of imports	103.57 (42.60)	108.69 (36.75)	n.a	n.a
Industry size	Industry employment as a percentage of total employment in the economy	20.26 (3.29)	15.52 (2.97)	64.13 (6.58)	71.58 (6.34)
Intermediate inputs	The difference between production (gross) and value added of goods and/or services produced in a year (estimated using input-output method)	272629.5 (401619.5)	471486 (692273.5)	326347.4 (516765.1)	748284.5 (1372506.0)

Source: own calculations based on OECD STAN Database 1987-2003
Averages reported; figures in parenthesis are standard deviations

Figure 3 - Overall change in R&D intensity (rdip) and Exports (xprod) over Exchange Rate Volatility (ex)

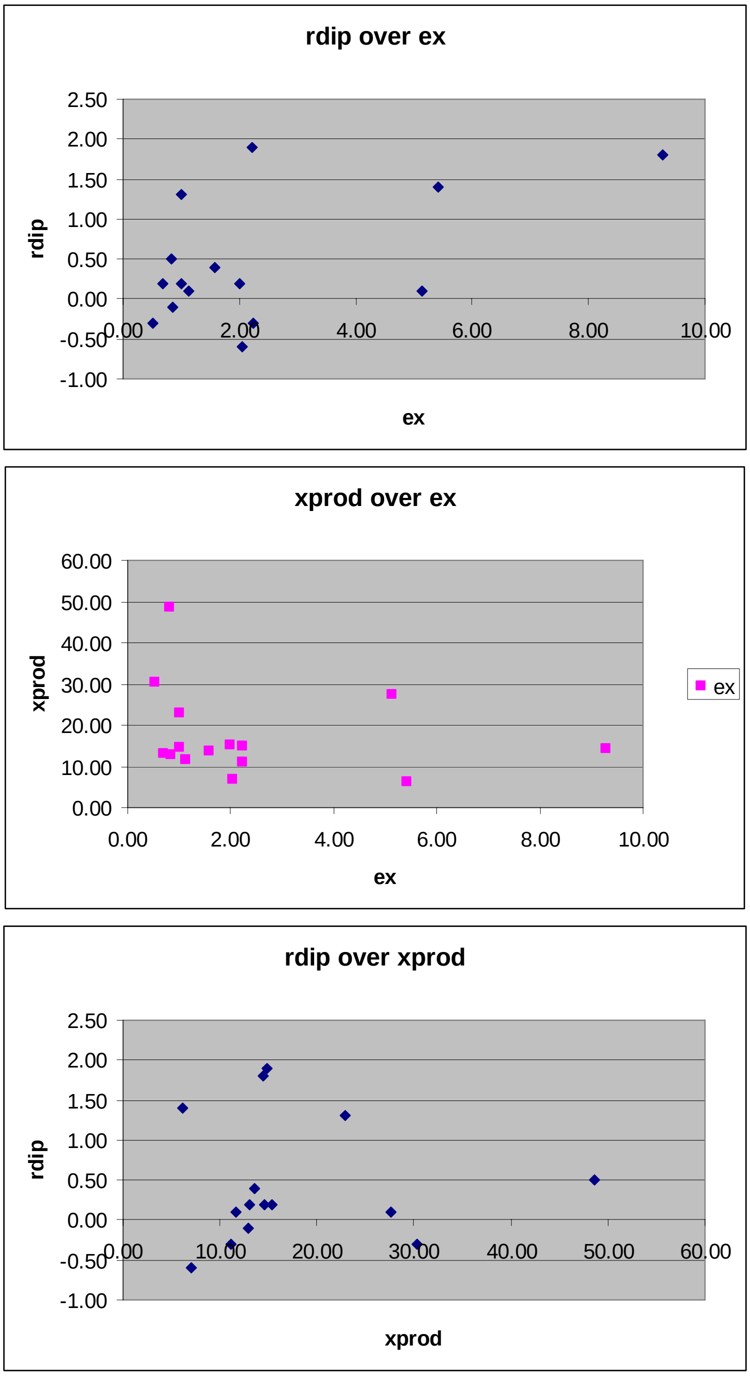


Table 2 - Panel regression estimates for Total Manufacturing and Total Services 1987-2003 : Random Effects Specifications

VARIABLES (dep: R&D intensity)	Total Manufacturing		Total Services
	Random Effects Spec.1	Random Effects Spec.2	Fixed effects
Ex-rate Volatility	-0.0106* (0.00558)	-0.01359* (.0059)	-0.00297 (0.00181)
Export Share in Production	0.0158*** (0.00342)		
Export-Import ratio		0.0016 (.0019)	
Industry Size [log(employees)]	-0.102 (0.229)	-0.375 (.219)	0.851*** (0.113)
Intermediate inputs	5.05e-08 (1.67e-07)	3.19e-07* (1.66e-07)	1.40e-07*** (2.63e-08)
Constant	2.234 (2.047)	5.076** (1.934)	-8.255*** (1.142)
Observations	215	215	197
Number of countries	14	14	14
R-square Within	0.22	0.13	0.504
R-square between	0.11	0.45	0.04
R-square overall	0.06	0.31	0.03

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$, Unbalanced Panel. The choice fixed versus random is based on Hausman test statistics.

Table 3 – Instrumental Variable Random Effects Panel Estimation on the Total Manufacturing Sector 1987-2003 (spec 1: Export share in production)

VARIABLES (dep: R&D intensity)	**Final Estimates**	**First Stage**
		Dep var: Export Share in Production
Export Share in Production	0.0569** (0.0276)	
Industry Size (logemp)	0.891 (0.713)	-24.13*** (4.30)
Intermediate inputs	-6.70e-07 (5.33e-07)	0.00002*** (3.13e-06)
Ex-rate Volatility		-0.258*** (0.1109)
Constant	-8.071 (7.231)	250.44*** (37.39)
Observations	215	215
Number of countries	14	
R-squared Within	0.15	
R-Square between	0.02	
R-Square overall	0.02	

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 4 – Instrumental Variables Random Effects Panel Estimation on the Total Manufacturing Sector 1987-2003

Specification 2 with Export-Import Ratio

VARIABLES (dep: R&D intensity)	Final Estimation	First stage
		Dep: Export-import Ratio
Export-import Ratio	0.0262* (0.0154)	
Industry Size (logemp)	0.0760 (0.236)	1.692 -6.351
Intermediate inputs	6.48e-08 (3.03e-07)	0.000012** (6.08e-06)
Ex-rate Volatility		-0.5164** (0.2157)
Constant	-1.542 (2.473)	95.92* (55.17)
Observations	215	
Number of countries	14	
R-squared Within	0.02	
R-squared Between	0.16	
R-squared Overall	0.14	

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

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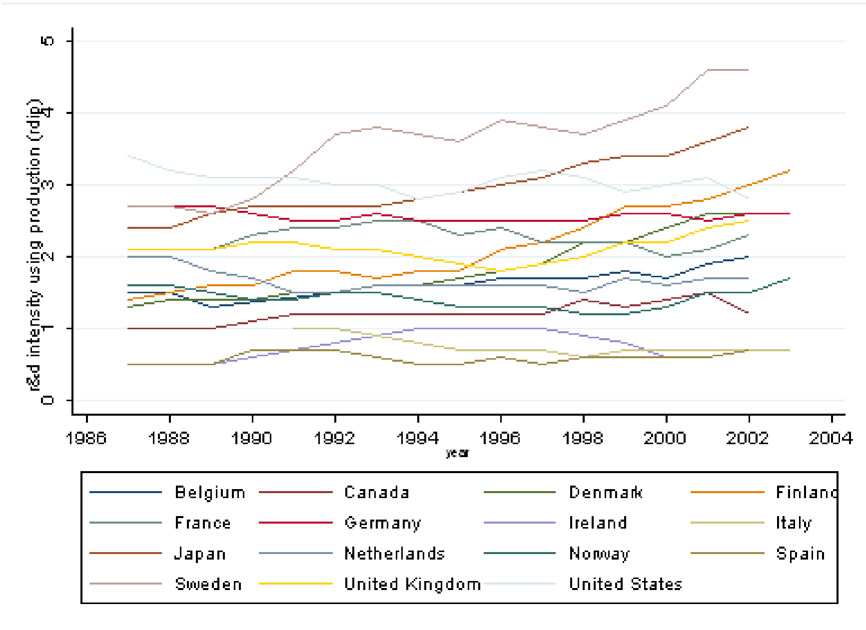
Figure A1 - Panel-line plots of R&D intensity country and year-wise comparison of manufacturing vs. services

Manufacturing



Services

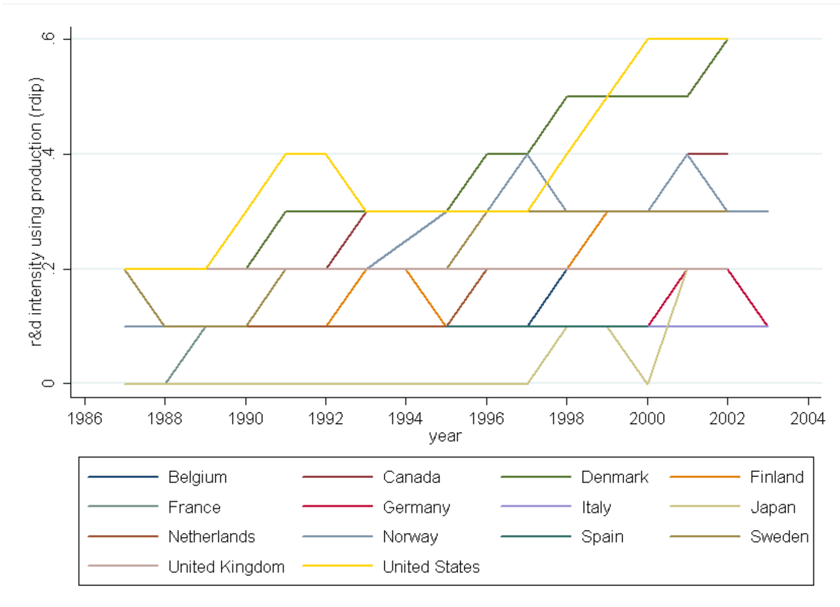


Figure A2 - Industry Size distributions (as measured by employment share relative to total employment in the whole economy)

Manufacturing Sector

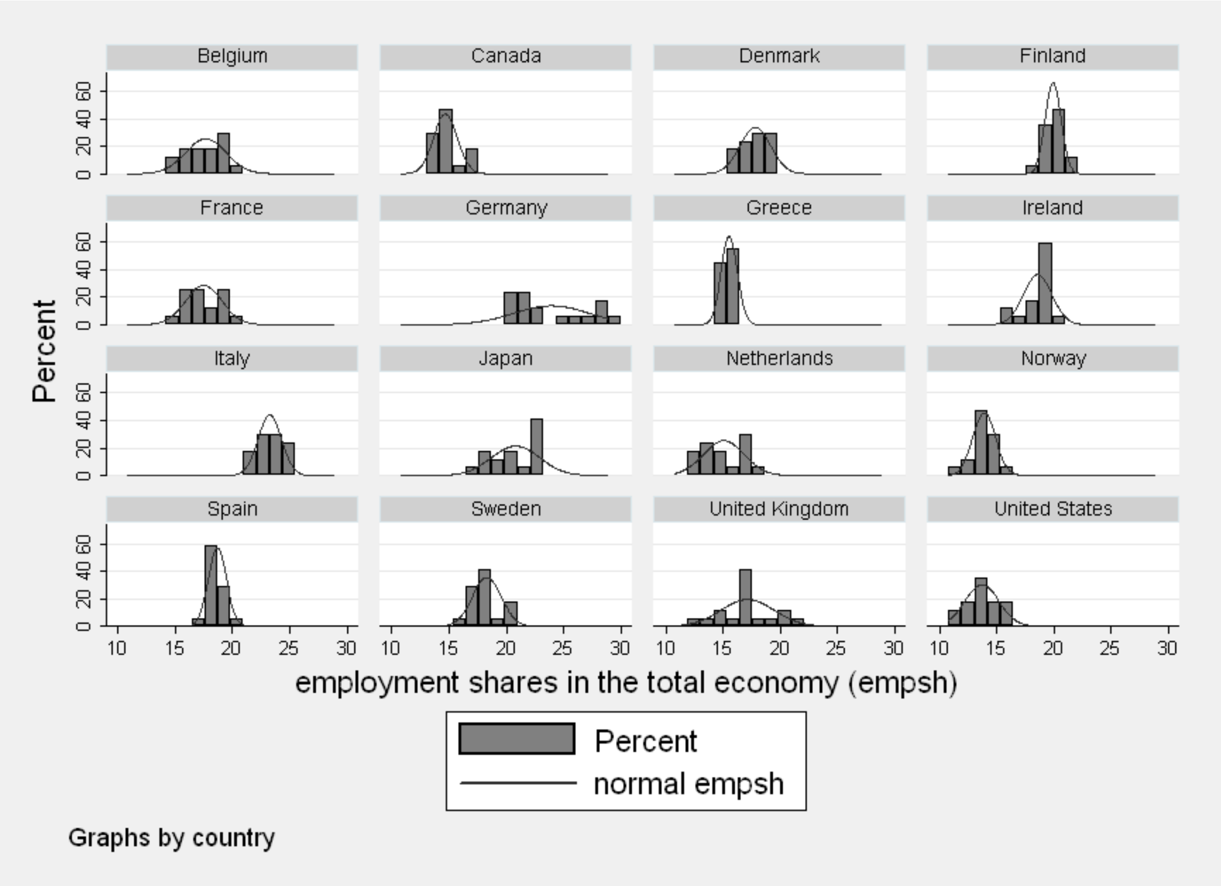


Figure A3 – Industry Size distributions (as measured by employment share relative to total employment in the whole economy)

Services Sector

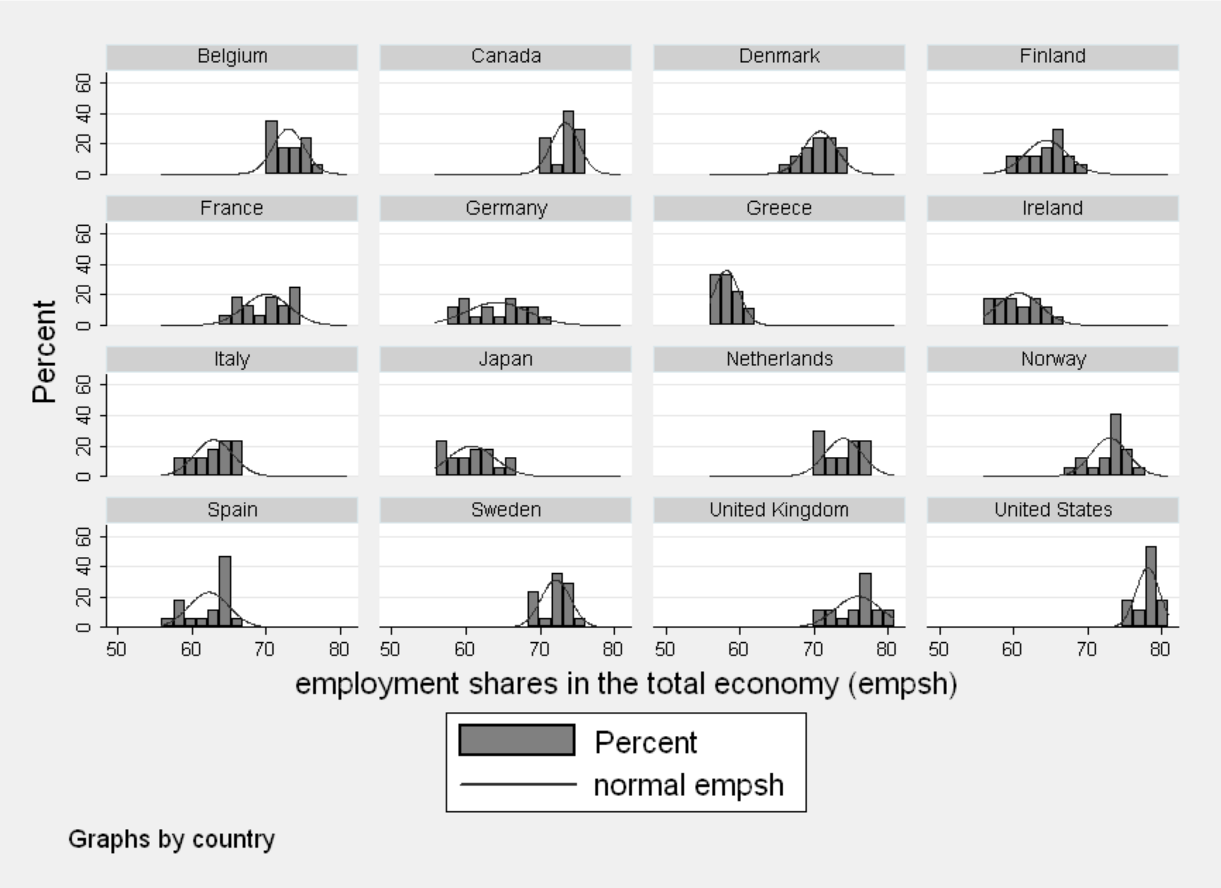


Table A1 - Robustness check of Table 2 results with fixed effects and pooled regression estimates accounting for cross-country effects.

	Manufacturing		Services	
VARIABLES	**Fixed Effects**	**Pooled**	**Fixed Effects**	**Pooled**
Volatility	-0.0134** (0.00520)	-0.0134** (0.00520)	-0.00297 (0.00181)	-0.00297 (0.00181)
Export share in prod	0.0119*** (0.00364)	0.0119*** (0.00364)	.	.
Industry Size	-1.333*** (0.323)	-1.333*** (0.323)	0.851*** (0.113)	0.851*** (0.113)
Intermediate inputs	-9.28e-09 (1.56e-07)	-9.28e-09 (1.56e-07)	1.40e-07*** (2.63e-08)	1.40e-07*** (2.63e-08)
Constant	13.08*** (2.874)	16.02*** (3.201)	-8.255*** (1.142)	-9.233*** (1.312)
Country Dummies included	.	YES		YES
Observations	215	215	197	197
Number of countries	14		14	
R-squared	0.27	0.92	0.51	0.82

Standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1