Exploring the nexus between appropriability and productivity in highly innovative and globalised companies

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Outline

1. Introduction and motivation
2. Literature
3. Empirical model
4. Conclusion

Motivation

What The paper investigate the the delicate balance between MNEs R&D activities, IPR protection and their impact on firm level labour productivity

Where We explore this relationship on data of most R&D intensive MNEs in the world, between 2007-2016 (COR&DIP database–JRC/OECD & ORBIS)

How We characterise the determinants of labour productivity as a function of tangibles, intangibles and the institutional context, whereby we explore potential non-linearities.

Why Lack of consensus in the literature on the role of appropriability in spurring innovation (Hall Sena 2017, Breschi Malerba Orsenigo 2000, Nelson Wolff 1997, Berge-Gill Lopez 2014, Gelabert Fosfuri Tribo 2009, Falk 2006, Cohen Walsh 2000, Cohen Nelson Walsh 2000, Ceccagnoli 2009)

The paper in a nutshell: contributions

Role of Appropriability (IPR) at the firm level
Identification of the role of appropriability at the level of the firm on productivity

Bright side The results show that patent protection could be beneficial in terms of productivity if associated to R&D expenditure, supporting the dual role (direct and indirect) of R&D at the firm level (Cohen Levinthal 1989)

Dark side The results also show the existence of non-linearities in the impact of R&D and IPR on productivity: too much patent protection ceases to be beneficial in terms of productivity even if associated with R&D expenditures

Methodological contribution The paper applies a methodology proposed by Amoroso Bruno Magazzini 2022 to identify time-invariant variables (TIV) in panel FE

Literature

- Productivity and R&D (Griliches 1979)
- R&D → productivity (Hall and Mairesse 1995; Crépon Duguet Mairesse 1998)
- Formal and Informal IPR, investment in R&D (Hall Sena 2017; Hall Helmers Rogers Sena 2013; Hall Helmers Rogers 2014)
- Schumpeter Hypotheses (Levin Cohen Mowery 1985; Nelson Wolff 1997; Breschi Malerba Orsenigo 2000; Berge-Gil Lopez 2014; Lee 2005):
  1. Market structure
  2. Role of demand
  3. Technology opportunities
  4. R&D appropriability
- Degree of Appropriability and effect on pulic R&D support (Gelabert Fosfuri Tribo 2009)
- Appropriability and performance (Griliches Cockburn 1988; Ceccagnoli 2009; Hall Sena 2017)

Model specification
(Hall Mairesse 1995)

- Dependent variable: Labour productivity (VA/emp.)
- Main independent variables:
  - R&D/emp (intangible)
  - Tangible capital (/emp)
  - Labour (emp)
- Moderation: Intellectual property rights as international patent systems strength
- Controls:
  - Unobserved heterogeneity: firms fixed effects
  - Time fixed effects
  - Sector trends (sector#time) Region trends (region#time) vs. use of country-industry deflators

Empirical analysis: determinants of productivity

- Data: COR&DIP database (JRC/OECD reports) merged with ORBIS & ORBIS-IP
- Starting from a sample of the top 2000 worldwide R&D spenders over the period 2007-2016
  - ▷ Missing values → 1000-1200 firms in the analysis
- Firm productivity as a function of tangibles, intangibles & appropriability (in logs, following the specification of Hall Mairesse, 1995)

$$\ln\left(\frac{VA}{L}\right) = \beta_1 \ln\left(\frac{K}{L}\right) + \beta_2 \ln\left(\frac{RD}{L}\right) + \beta_3 \ln(L) + \beta_4 App + \beta_5 \ln\left(\frac{RD}{L}\right) \times App + \varepsilon$$

How to measure appropriability?

- Measure of the IP-environment faced by the firms
- We rely on two measures of "appropriability" based on measurement of the international patent systems strength (country-level information)

EFW: Economic Freedom Index, by World Economic Forum

Survey of business executives asked to rate the extent to which a country's legal framework allows individuals to acquire, hold, and utilize private property and the extent to which these rights are secured by clear laws that the government enforces effectively

(1-7; 151 countries, 2007-2017)

PEI: Patent Enforcement Index by Papageorgiadis Sofka (2020)

Patent system strength as determined by laws and enforcement – degree to which patents confer rights to their holders, but also how effectively and efficiently they can be enforced

(0-10; 51 countries, 1998-2017)

- In our sample, the correlation between the two measures is 0.95

How to measure appropriability?

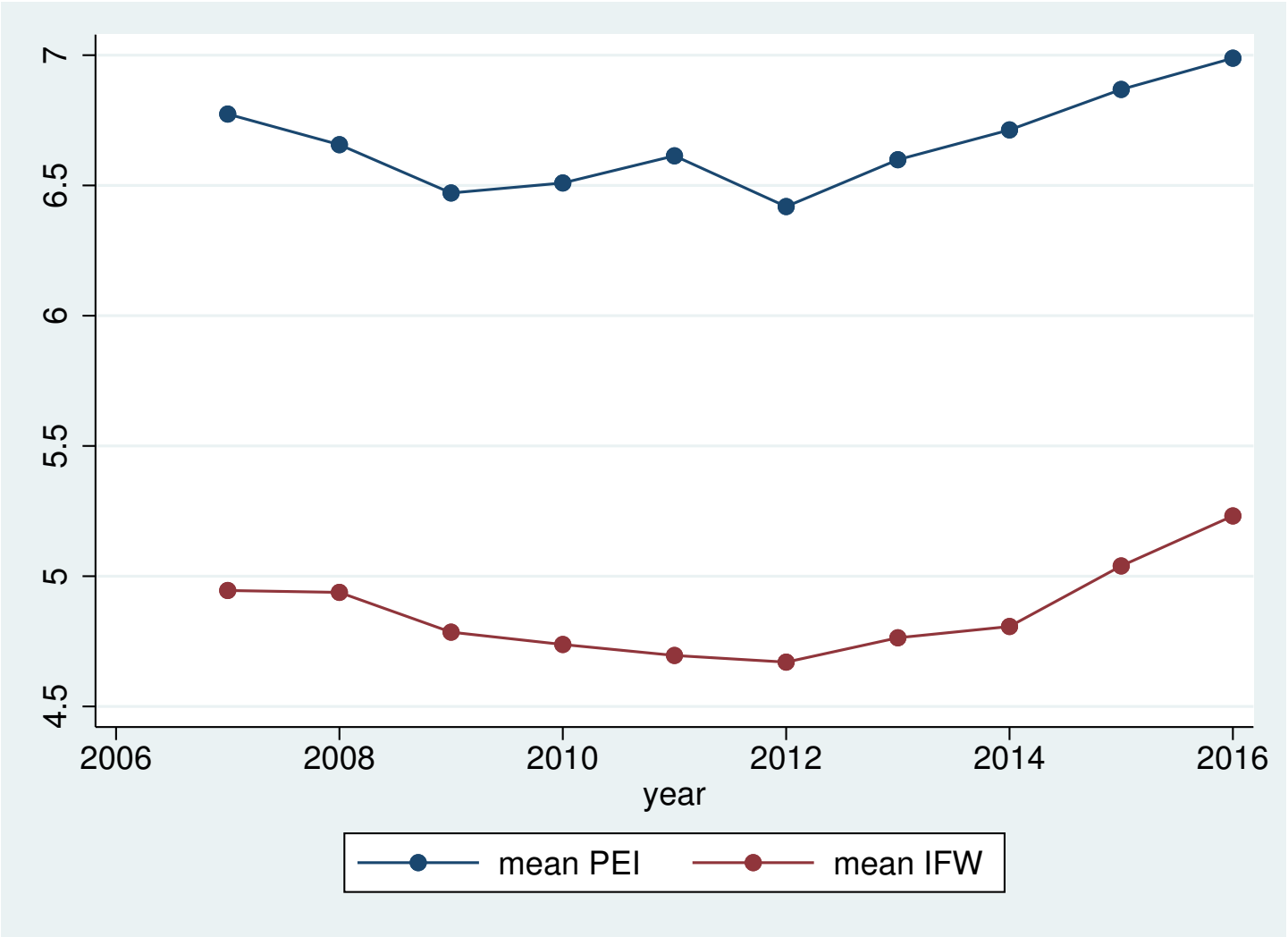
The IP-environment faced by the firm

- To build a measure of appropriability at the firm level, PEI and EFW are weighted on the basis of firm's patenting across countries (Bruno et. al. 2022)

$$App_{it} = \sum_c \frac{\#Pt_{ict}}{\#Pt_{it}} App_{ct} = \sum_c s_{ict} App_{ct}$$

  - App_{ct} is, respectively, EFW and PEI, in country c at time t
  - $\#Pt_{ict}$: number of patent of firm i at time t granted in country c
  - $\#Pt_{it}$: total number of patent of firm i at time t
- App_{it}: weighted average of the IPR strength in the countries in which firm i chooses to protect its rights at time t
  - Endogeneity concerns – to be discussed later
- At the firm level, correlation equals 0.78

Evolution of patent protection at the firm level



Baseline results – PEI

Variable	orig.	imput.	defl.	defl.
$\ln(K/L)$	.533***	.529***	.572***	.572***
	(.030)	*(.030)*	*(.032)*	*(.032)*
$\ln(RD/L)$	.527***	.488***	.315*	.382*
	(.160)	*(.157)*	*(.170)*	*(.161)*
$\ln(L)$	-.058	-.088	-.122	
	(.103)	*(.099)*	*(.098)*	
App_{it}	.362	.335	.233	.220
	(.247)	*(.243)*	*(.171)*	*(.170)*
$\ln(RD/L)$	-.029	-.027	-.031	-.030
$\times App$	*(.022)*	*(.021)*	*(.024)*	*(.024)*
N	7058	7446	5846	5846

Note: time FE included in all specifications.
Orig. & imputed also includes sector× year, region× year.

Baseline results – EFW

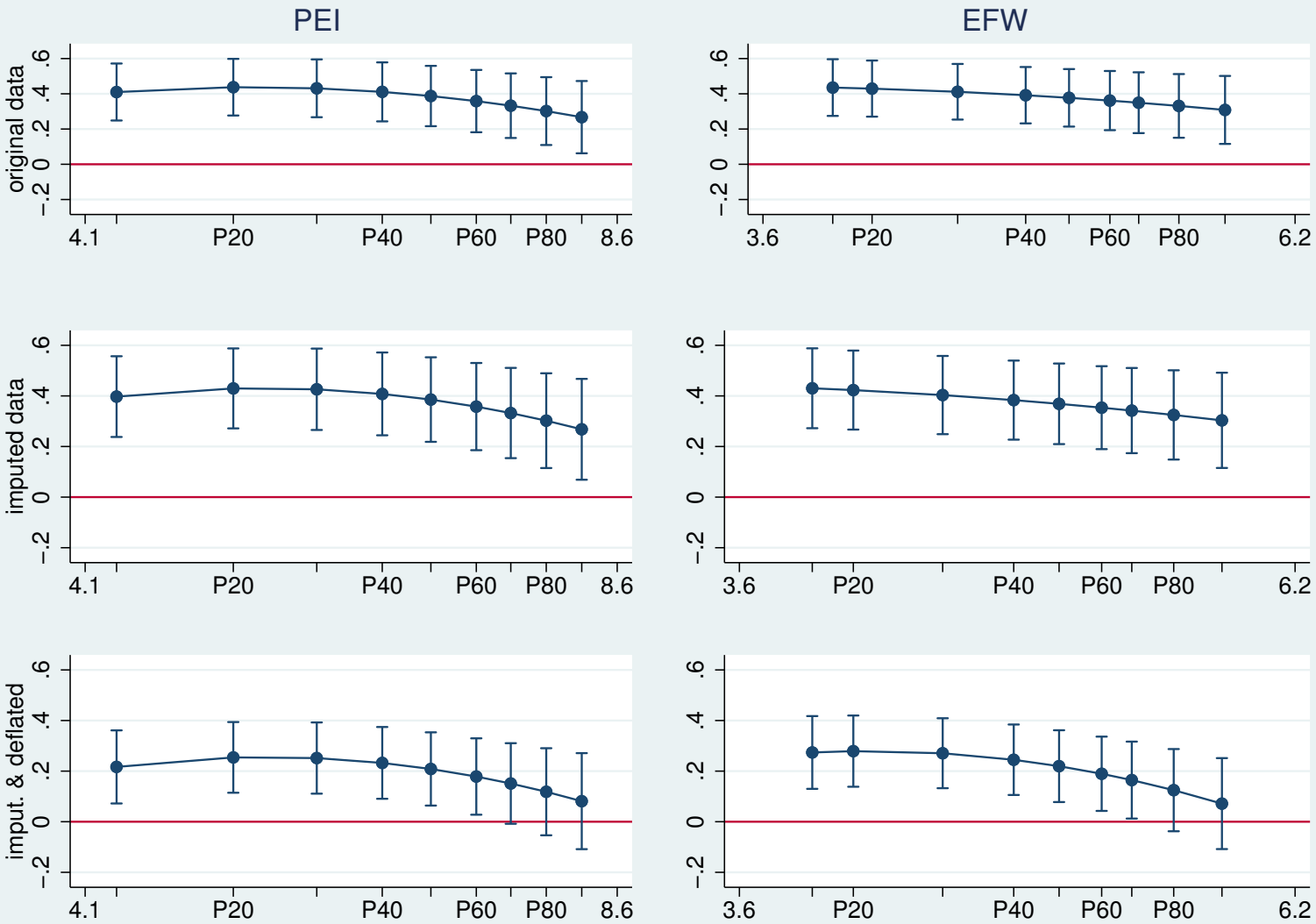
Variable	orig.	imput.	defl.	defl.
$\ln(K/L)$	.530***	.527***	.572***	.572***
	(.030)	*(.030)*	*(.032)*	*(.032)*
$\ln(RD/L)$	.567***	.560***	.507***	.577***
	(.183)	*(.176)*	*(.191)*	*(.184)*
$\ln(L)$	-.051	-.084	-.140	
	(.103)	*(.099)*	*(.097)*	
App_{it}	.627*	.660*	.645**	.616**
	(.378)	*(.365)*	*(.259)*	*(.260)*
$\ln(RD/L)$	-.044	-.048	.083**	-.080**
$\times App$	*(.033)*	*(.032)*	*(.037)*	*(.037)*
N	7044	7431	5845	5845

Note: time FE included in all specifications.
Orig. & imputed also includes sector× year, region× year.

$$\begin{aligned}\ln\left(\frac{VA}{L}\right) &= \beta_1 \ln\left(\frac{K}{L}\right) + \beta_2 \ln\left(\frac{RD}{L}\right) + \beta_3 \ln(L) \\ &\quad + \beta_4 App + \beta_5 App \times \ln\left(\frac{RD}{L}\right) \\ &\quad + \beta_6 App^2 + \beta_7 App^2 \times \ln\left(\frac{RD}{L}\right) + \varepsilon\end{aligned}$$

Exploring non-linearities

Polynomial modeling: APE of ln(RD) as a function of *App*



- On the basis of previous results, we selected three "levels": (i) below the median; (ii) between 2nd and 3rd quartile (median to P75); (iii) above 3rd quartile

$$\begin{aligned}\ln\left(\frac{VA}{L}\right) &= \beta_1 \ln\left(\frac{K}{L}\right) + \beta_2 \ln\left(\frac{RD}{L}\right) + \beta_3 \ln(L) \\ &\quad + \beta_4 A_{(Q2.Q3)} + \beta_5 A_{(Q2.Q3)} \times \ln\left(\frac{RD}{L}\right) \\ &\quad + \beta_6 A_{(Q3+)} + \beta_7 A_{(Q3+)} \times \ln\left(\frac{RD}{L}\right) + \varepsilon\end{aligned}$$

Exploring non-linearities

Dummy for selected thresholds – PEI

Variable	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	$.532^{***}$	$.528^{***}$	$.571^{***}$	$.571^{***}$
	(.030)	*(.030)*	*(.032)*	*(.032)*
$\ln(RD/L)$	$.390^{***}$	$.364^{***}$	$.164^{*}$	$.236^{***}$
	(.111)	*(.108)*	*(.088)*	*(.069)*
$\ln(L)$	-.045	-.075	-.114	
	(.103)	*(.099)*	*(.098)*	
$A_{(Q2.Q3)}$	.773	.682	$.685^{*}$	$.668^{*}$
	(.584)	*(.563)*	*(.363)*	*(.364)*
$A_{(Q3+)}$	1.61^{**}	$\dot{5}79^{**}$	$.820^{*}$	$.821^{*}$
	(.689)	*(.683)*	*(.463)*	*(.460)*
$A_{(Q2.Q3)} \times \ln(RD/L)$	-.063	-.054	$-.091^{*}$	$-.089^{*}$
	(.052)	*(.050)*	*(.053)*	*(.054)*
$A_{(Q3+)} \times \ln(RD/L)$	$-.136^{**}$	$-.133^{**}$	$-.112^{*}$	$-.113^{*}$
	(.061)	*(.060)*	*(.066)*	*(.066)*
N	7058	7446	5846	5846

Exploring non-linearities

Dummy for selected thresholds – EFW

Variable	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	$.529^{***}$	$.527^{***}$	$.5703^{***}$	$.571^{***}$
	(.030)	*(.030)*	*(.032)*	*(.032)*
$\ln(RD/L)$	$.400^{***}$	$.377^{***}$	$.176^{**}$	$.259^{***}$
	(.111)	*(.109)*	*(.089)*	*(.070)*
$\ln(L)$	-.056	-.088	-.131	
	(.101)	*(.098)*	*(.097)*	
$A_{(Q2.Q3)}$	.758	.721	$.635^{**}$	$.626^{**}$
	(.524)	*(.507)*	*(.302)*	*(.301)*
$A_{(Q3+)}$	1.88^{***}	1.88^{***}	1.31^{***}	1.30^{***}
	(.659)	*(.641)*	*(.414)*	*(.413)*
$A_{(Q2.Q3)} \times \ln(RD/L)$	-.057	-.054	$-.090^{**}$	$-.088^{**}$
	(.046)	*(.045)*	*(.044)*	*(.044)*
$A_{(Q3+)} \times \ln(RD/L)$	$-.146^{**}$	$-.148^{***}$	$-.168^{***}$	$-.167^{***}$
	(.058)	*(.056)*	*(.059)*	*(.059)*
N	7044	7431	5845	5845

Endogeneity concerns

- Firms *choose* the countries in which to protect their innovation
- Endogeneity concerns related to the measure of appropriability
- Two strategies

1. Build an exogenous measure of appropriability
   - ▷ Build a model for firm's patenting at the country level:

$$\begin{aligned} Pt_{ict} \quad = \quad & f(\ln(RD)_{it}, \ln(\bar{R}D)_{i}, \ln(GDP)_{ct}, \ln(GDP)_{it}, \\ & dist_{ic}, \alpha_c, D(cty_i), \tau_t) \end{aligned}$$

   - ▷ Use fitted number of patents to build the weights:

$$\hat{A}_{it} = \sum_c \frac{\#\hat{P}t_{ict}}{\#\hat{P}t_{it}} App_{ct}$$

2. Exploit pre-sample information available for PEI

Robustness checks

Exogenous measure of appropriability – PEI

Variable	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	.514***	.513***	.573***	.573***
	(.031)	*(.031)*	*(.032)*	*(.032)*
$\ln(RD/L)$	.386***	.356***	.148*	.230***
	(.116)	*(.112)*	*(.089)*	*(.072)*
$\ln(L)$	-.059	-.091	-.129	
	(.105)	*(.100)*	*(.098)*	
$\hat{A}_{Q2.Q3}$	.566	.533	.740***	.727***
	(.384)	*(.383)*	*(.237)*	*(.238)*
$\hat{A}_{Q3+}$	1.07	.873	.145	.116
	(1.03)	*(.860)*	*(.539)*	*(.544)*
$\hat{A}_{Q2.Q3} \times \ln(RD/L)$	-.069**	-.066*	-.109***	.108***
	(.034)	*(.034)*	*(.036)*	*(.036)*
$\hat{A}_{Q3+} \times \ln(RD/L)$	-.103	-.084	-.011	-.009
	(.093)	*(.077)*	*(.078)*	*(.079)*
N	6788	7171	5839	5839

Robustness checks

Exogenous measure of appropriability – EFW

Variable	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	.515***	.513***	.569***	.569***
	(.031)	*(.031)*	*(.032)*	*(.032)*
$\ln(RD/L)$	.389***	.360***	.126	.205***
	(.116)	*(.112)*	*(.087)*	*(.070)*
$\ln(L)$	-.055	-.087	-.123	
	(.105)	*(.101)*	*(.099)*	
$\hat{A}_{Q2.Q3}$	.299	.288	-.067	-.078
	(.401)	*(.384)*	*(.224)*	*(.225)*
$\hat{A}_{Q3+}$	.456	.425	.855***	.847***
	(.540)	*(.520)*	*(.285)*	*(.286)*
$\hat{A}_{Q2.Q3} \times \ln(RD/L)$	-.052	-.051	.005	.007
	(.034)	*(.032)*	*(.032)*	*(.032)*
$\hat{A}_{Q3+} \times \ln(RD/L)$	-.070	-.067	-.108***	-.108***
	(.043)	*(.041)*	*(.039)*	*(.039)*
N	6788	7171	5839	5839

Robustness checks: pre-sample value (PEI only)

- To mitigate endogeneity concerns, we exploit the availability of pre-sample information on PEI (average 2000-2006)
- Interaction term is identified in a FE framework, however the effect of time-invariant variables cannot be identifies
  - ▷ Unless additional assumptions are imposed (e.g., Hausman Taylor 1981, Pesaran Zhou 2018)
- We exploit the framework in Breusch Mizon Schmidt 1989 to also identify the effect of appropriability
  - ▷ Need to find variable(s) with *homogenous* correlation with individual component

Identification of time-invariant variables

(Amoroso Bruno Magazzini 2022)

$$y_{it} = \mathbf{x}'_{it}\beta + \mathbf{z}'_i\gamma + \varepsilon_{it} = \mathbf{x}'_{it}\beta + \mathbf{z}'_i\gamma + \tau_t + \alpha_i + e_{it}$$

- FE as IV with $\mathbf{x}_{it} - \bar{\mathbf{x}}_i$ as instruments (γ not identified)
- Seminal work by Hausman Taylor 1981

$$\mathbf{x}_{it} = (\mathbf{x}_{1it}, \mathbf{x}_{2it}) \quad \& \quad \mathbf{z}_i = (\mathbf{z}_{1i}, \mathbf{z}_{2i})$$

- Need to make assumption: $\mathbf{x}_{1it}$ and $\mathbf{z}_{1i}$ uncorrelated with α_i
- IV estimation with instruments $\mathbf{x}_{1it} - \bar{\mathbf{x}}_{1i}$, $\mathbf{x}_{2it} - \bar{\mathbf{x}}_{2i}$, $\mathbf{x}_{1it}$ and $\mathbf{z}_{1i}$
- Set of instruments extended by Amemiya MaCurdy 1986 and Breusch Mizon Schmidt 1989

Identification of time-invariant variables

(Amoroso Bruno Magazzini 2022)

- Breusch Mizon Schmidt 1989: assuming, for all i, $E(\mathbf{x}_{2it}\alpha_i)$ is the same for all t, the set of instrumental variables can be extended to include

$$\mathbf{x}_{2i1} - \bar{\mathbf{x}}_{2i},\ \mathbf{x}_{2i2} - \bar{\mathbf{x}}_{2i}, ..., \mathbf{x}_{2iT} - \bar{\mathbf{x}}_{2i}$$

- When only "2" vars. are available – Estimate β by:

$$E[(x_{it} - \bar{x}_i)(y_{it} - \beta x_{it} - \gamma z_i)] = 0$$

(γ not identified)

- Exploit the additional "BMS" conditions to identify γ

$$E[(x_{i2} - \bar{x}_i)(y_{it} - \beta x_{it} - \gamma z_i)] = 0$$

$$\dots$$

$$E[(x_{iT} - \bar{x}_i)(y_{it} - \beta x_{it} - \gamma z_i)] = 0$$

Robustness checks: pre-sample value (PEI only)

Results – imp. & defl. data (Amoroso Bruno Magazzini 2022)

Variable	2SLS	LIML	2SLS	LIML
$\ln(K/L)$	.576***	.576***	.577***	.577***
	(.032)	*(.032)*	*(.032)*	*(.032)*
$\ln(RD/L)$	.569**	.597**	-.014	-.030
	(.229)	*(.240)*	*(.090)*	*(.104)*
$\ln(L)$	-.088	-.097	-.117	-.139
	(.280)	*(.310)*	*(.135)*	*(.161)*
$\bar{A}_{00.06}$	.602***	.630***		
	(.183)	*(.191)*		
$\bar{A}_{00.06} \times \ln(RD/L)$	-.090***	-.096***		
	(0.034)	*(.036)*		
$\bar{A}^{00.06}_{Q2.Q3}$			.376	.340
			(.885)	*(.985)*
$\bar{A}^{00.06}_{Q3+}$			1.08	1.29
			(1.02)	*(1.21)*
$\bar{A}^{00.06}_{Q2.Q3} \times \ln(RD/L)$			-.039	-.036
			(.153)	*(.173)*
$\bar{A}^{00.06}_{Q3+} \times \ln(RD/L)$			-.170	-.210
			(.167)	*(.201)*
N	5848	5848	5848	5848
Hansen-j (p)	.173	.185	.355	.380
KP F-stat.	>1,000	>1,000	47.3	47.3

Conclusion and further work

- We have identified a complex empirical relationship between R&D and productivity, especially when looking into the role of IPR
  - Patent protection could be beneficial in terms of productivity if associated with R&D expenditure, supporting the dual role (direct and indirect) of R&D at the firm level (Cohen Levinthal 1989)
  - However, non-linearities exist in the relationship between R&D, IPR and productivity: too much patent protection ceases to be beneficial in terms of productivity even if associated with R&D expenditures
- Further work
  - Better identification of the channels through which IPR "operates"
  - Better identification of the channels through which IPR interacts with R&D

Thank you

Source of data key references

- Dernis, Dosso, Hervás, Millot, Squicciarini and Vezzani (2015). *World Corporate Top R&D Investors: Innovation and IP bundles*, a JRC and OECD common report. Luxembourg: Publications Office of the European Union.
- Dernis, Gkotsis, Grassano, Nakazato, Squicciarini, van Beuzekom and Vezzani (2019). *World Corporate Top R&D investors: Shaping the Future of Technologies and of AI*, a joint JRC and OECD report. EUR 29831 EN, Publications Office of the European Union, Luxembourg.
- Hernández, Grassano, Tübke, Amoroso, Csefalvay, and Gkotsis: *The 2019 EU Industrial R&D Investment Scoreboard*, EUR 30002 EN; Publications Office of the European Union, Luxembourg, 2020.
- *World Corporate Top R&D Investors: Industrial Property Strategies in the Digital Economy*, JRC/OECD COR&DIP©Database, v.2. 2019