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RESEARCH INFRASTRUCTURE FOR SCIENCE
AND INNOVATION POLICY STUDIES

Panel Data Methods and Applications

Massimiliano Guerini

Online Course

DAY1 - November 19th, 2020

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Introduction

What is this course about?

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- The **aim** of this RISIS short course is to provide an overview on panel data models

- The course will cover the following **topics**:
  - Conceptual bases on panel data (definitions)
  - Key estimators (RE, FE, hints on IV and Dynamic Panel Models)
  - Presentation of examples/use cases
  - Training on panel data analysis in STATA using VICO dataset

- At the end of the course, students are expected to be able to apply panel data models and to interpret the results from them

RISIS Project

- This course is part of the **Training Activities** of the H2020 EU-funded **RISIS2** Project (http://risis2.eu)

RISIS Project

- RISIS2 is a **EU-funded H2020** project that gathers 18 partners aiming to transform the field of STI studies into an **advanced research community**

- We intend to achieve this objective by:
  - Developing an **e-infrastructure** that supports full virtual transnational access by researchers
  - Providing a vastly **enlarged set of services** tailored to field-specific needs (e.g. for supporting analytical capabilities of researchers)
  - Maintaining/developing **datasets** dealing with firm innovation capacities, social innovation, public research developments, R&I outputs and projects, and policy learning

Panel data in RISIS

- A few examples:
  - **VICO:** Data on Venture Capital investments and the performance of funded startups
  - **Cheetah:** Data on fast-growing medium-sized firms across time
  - **CIB/CinnoB:** Data and indicators at the firm level for the worldwide largest R&D corporate performers
  - **ETER:** Higher education/University register, with information on both input and output measures across time
  - **KNOWMAK:** Dynamics of scientific/technological productivity in EU regions
  - …

- **Interested in RISIS datasets? Go to https://rcf.risis2.eu/datasets**

Course structure

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Day 1 – November 19th, 2020
10:00-10:30 – Introduction
10:30-11:45 – Panel data structure and main panel data models/estimators
11:45-12:00 – Break
12:00-13:00 – Examples of applications in the context of Venture Capital

Day 2 – November 20th, 2020
10:00-11:30 – Practical session using STATA and VICO dataset (I)
11:30-11:45 – Break
11:45-12:45 – Practical session using STATA and VICO dataset (II)
12.45-13.00 – Introduction to group assignment

Remote workgroup
Students will have 1 week to work remotely on the assignment. During this week, groups will have 1 hour dedicated session of tutoring with course instructors.

Day 3 – November 26th, 2020
10:00-11:30 – Group presentations
11:30-12:00 – Closing Remarks

Instructors

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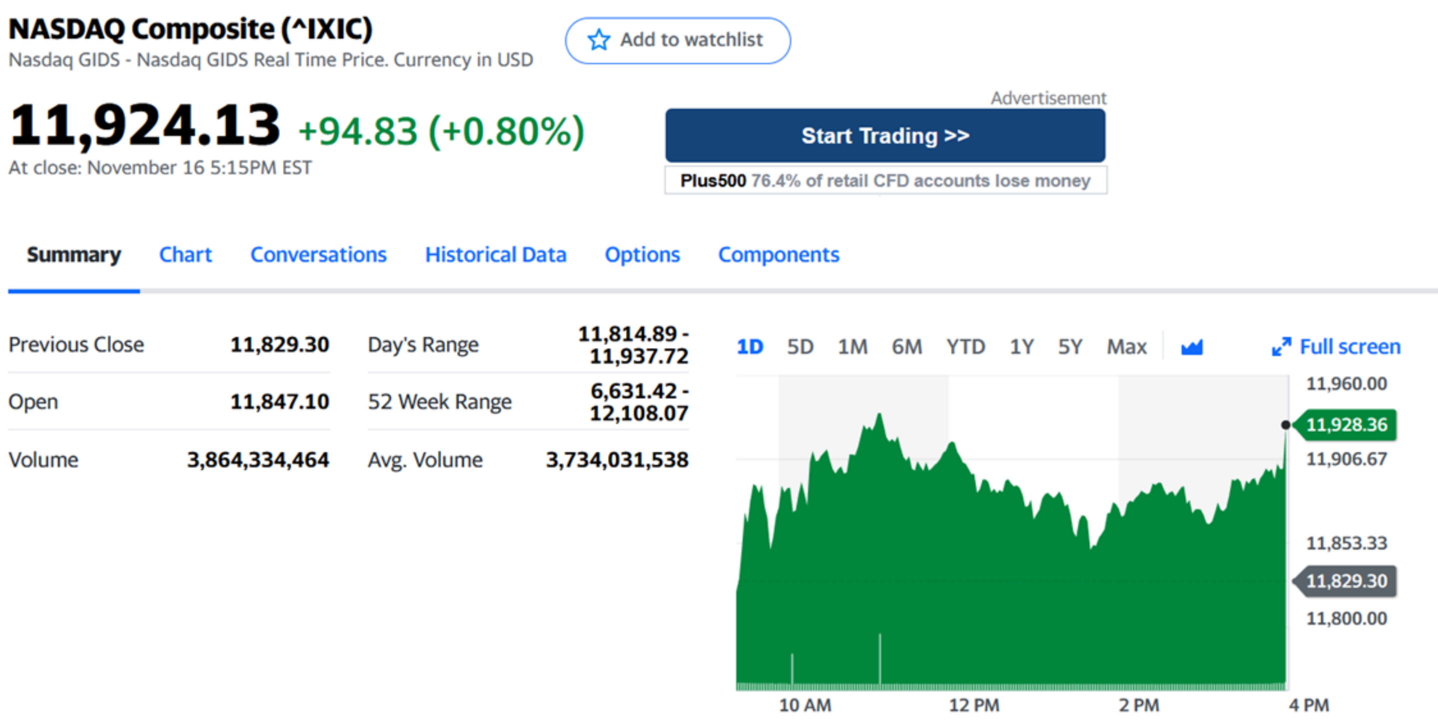
Panel Data Structure

Type of data

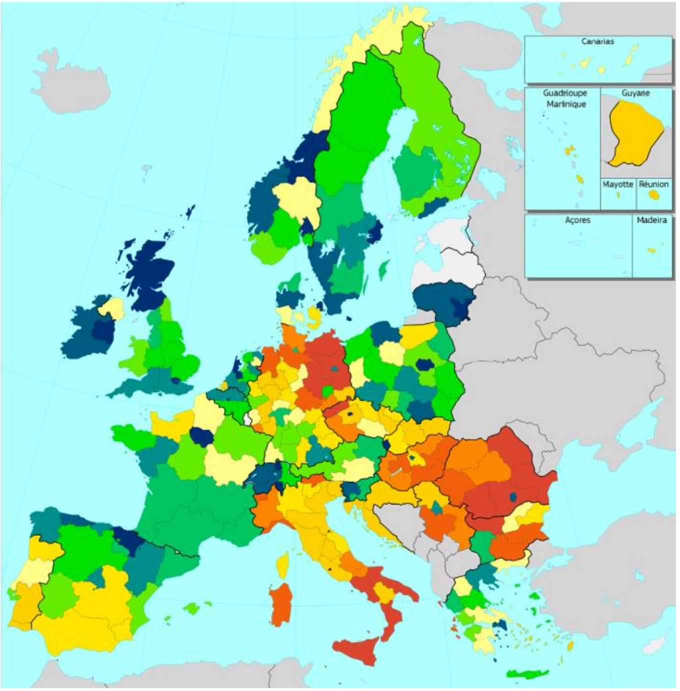
- **Time-series data:** A collection of observations for a single entity obtained through repeated measurements over time
  - The interest lies in modelling the path over time



Type of data

- **Cross-sectional data:** A collection of observations for multiple entities at a single point in time
  - The interest lies in modeling the heterogeneity across entities

Percentage population aged 30-34 having completed tertiary education



What are Panel Data?

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- **Panel data** (a.k.a. longitudinal or cross-sectional time-series data) are data that have both a **cross-sectional** and a **time series** dimension

- **Multiple entities are observed for multiple periods of time**
  - Entities could be countries, regions, companies, universities or individuals…

- Standard notation:
  - Entities (i) observed across time (t)
  - Dependent variable: Y_{it}
  - Independent regressors: X_{it}
  - for $i = 1, ..., N$ and $t = 1, ..., T$

Basic concepts

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- **Short panel:** a (relatively large) number of cross-section entities are observed during a (relatively short) period of time
  - Eg. 10,000 firms observed for 10 years

- Variables/parameters may vary over entities or time
  - **Within** variation: same entity, across time (e.g. measuring firm growth in size)
  - **Between** variation: across entities (e.g. comparing the size of different firms)

- **Dynamic models:** regressors include lagged dependent variable
  - Euler equations for modelling firm investment decisions
  - Empirical models of economic growth

Balanced vs. Unbalanced

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Balanced panel data

ID	Year	Income	Age	Gender
1	2014	1500	27	0
1	2015	1600	28	0
1	2016	2000	29	0
2	2014	2100	38	1
2	2015	2400	39	1
2	2016	2500	40	1

Unbalanced panel data

ID	Year	Income	Age	Gender
1	2014	1500	27	0
1	2016	2000	29	0
2	2014	2100	38	1
2	2015	2400	39	1
2	2016	2500	40	1
3	2016	2100	41	0

Long vs. Wide

Long format

ID	Year	Income	Age	Gender
1	2014	1500	27	0
1	2015	1600	28	0
1	2016	2000	29	0
2	2014	2100	38	1
2	2015	2400	39	1
2	2016	2500	40	1

Wide format

ID	Income2014	Income2015	Income2016	Gender
1	1500	1600	2000	0
2	2100	2400	2500	1
3	1900	1850	1700	0
4	2315	2400	3000	1

Panel data models

- **Why using panel data?** Richer models and estimation methods!
  - Possibility to introduce dynamic specifications
  - Causation from observational data: possibility to control for individual unobserved heterogeneity

- **However, panel data requires specific econometric models in order to assess causation**

- **Panel Data Models** are methodological approaches for analyzing panel data

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Panel Data Models and Estimators

Pooled OLS model

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- Let us first consider a basic model is as follows:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \varepsilon_{it}$$

- Where:
  - Y_{it} is the dependent variable
  - X_{it} is the independent variable
  - β_1 is the coefficient for the independent variable
  - β_0 is the intercept
  - ε_{it} is the error term (due to the fact that there are some unobservable factors that we are not able to measure)

Pooled OLS model

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- **Can we estimate the beta coefficients using OLS regression (*regress* in STATA)?**

- Pooled OLS model is one where the data on different units are pooled together
  - Basically we are treating all observations as they were cross-sectional units

- It implies strong assumptions on the error term ε_{it}:
  - Homoschedasticity and no autocorrelation of errors across observations
  - Exogeneity of X_{it}, i.e. the explanatory variable X_{it} is not correlated with the error term

Two main issues with panel data

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- Contrary to cross-section data, **the same entity is repeatedly observed**
  - The assumption of no autocorrelations of error across observations fails (as there are observations that refer to the same entity)
  - <u>Pooled OLS is inefficient</u> (standard errors are not estimated properly)

- **Endogeneity**
  - Unobserved factors might be correlated with regressors
  - **Not only in panel…** but panel data methods offer more opportunities for solving this issue (and for properly assessing **causal relations** using observational data)
  - <u>Pooled OLS is inconsistent</u> (wrong coefficients)

Decomposition of the error term

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- Let us now decompose the error term in two distinct components:

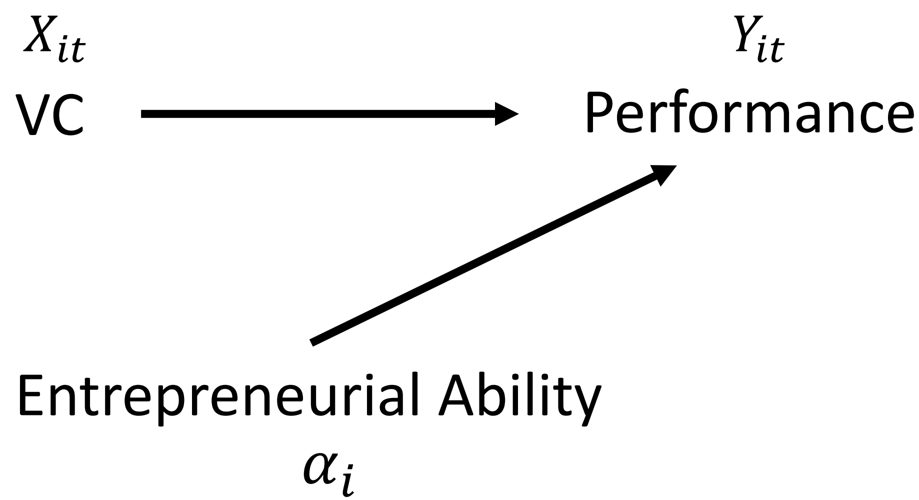
$$\varepsilon_{it} = \alpha_i + u_{it}$$

- u_{it} is the idiosyncratic error term that varies across individuals and time:
  - It is assumed to be uncorrelated with X_{it}

- α_i is the unobserved entity-specific time-constant error term:
  - The value α_i is specific for each entity *i*
  - Due to α_i, **the assumption of independent errors across observations fails**

Decomposition of the error term

- Suppose we are interested in estimating the impact of VC financing on firm performance:



- For sure there might be some variables that influence performance, but that we are not able to observe
  - Given that α_i is not observable, all the error terms that refer to the entity *i* will be somewhat correlated

Random Effect (RE) model

- Standard equation for RE model is as follows:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \underbrace{\alpha_i + u_{it}}_{\varepsilon_{it}}$$

- Where:
  - Y_{it} is the dependent variable
  - X_{it} is the independent variable
  - β_1 is the coefficient for the independent variable
  - β_0 is the intercept
  - ε_{it} is the error term, disaggregated in the two components α_i and u_{it}

- **Key assumption: α_i are i.i.d. random-effects not correlated to X_{it}**

Random Effect (RE) model

- In RE, the unobserved heterogeneity (variation across entities) is assumed to be random and uncorrelated with regressors included in the model – exogeneity
  - As long as these assumptions hold the **estimates from RE are efficient**

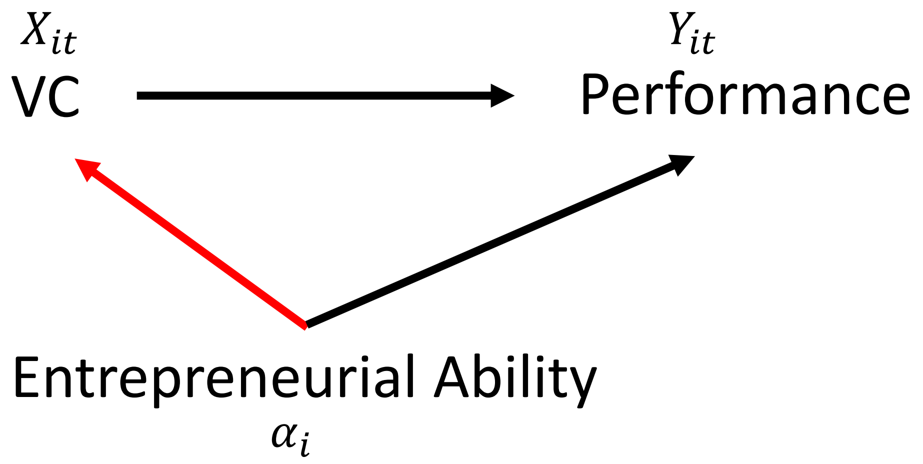
- The model can be estimated by (feasible) GLS (*xtreg, re* in STATA)

- With respect to OLS, there is only one additional parameter to be estimated: σ_α (which is used to correct standard errors)

Random Effect (RE) model

- There are relevant cases where this exogeneity assumption is likely to be violated

- Suppose again we are interested in estimating the impact of VC financing on firm performance:



- If entrepreneurial ability (not observable) is positively correlated with both VC and Performance, RE coefficients are upward biased

Fixed Effect (FE) model

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- Standard equation for FE model is as follows:

$$Y_{it} = \beta_1 X_{it} + \underbrace{\alpha_i + u_{it}}_{\varepsilon_{it}}$$

- Where:
  - Y_{it} is the dependent variable
  - X_{it} is the independent variable
  - β_1 is the coefficient for the independent variable
  - α_i is the unobserved entity-specific time-constant error term. **It can be correlated with $\boldsymbol{X_{it}}$**
  - u_{it} is the idiosyncratic error term that varies across individuals and time. It is assumed to be uncorrelated with X_{it}

Fixed Effect (FE) model

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- Ideally, if we could include in the econometric specification a dummy variable for each entity the unobserved entity-specific heterogeneity would be controlled for with a simple OLS regression

- The equation for the FE model would become (**Least Squares Dummy Variables LSDV - estimator**):

$$Y_{it} = \beta_1 X_{it} + \alpha_1 + \alpha_2 D_2 + \cdots + \alpha_N D_N + u_{it}$$

- However, when T is small and N is large this model cannot be estimated

Fixed Effect (FE) model

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- **A solution is to eliminate the fixed characteristics** α_i through mean-differencing (**Within Group estimator**)
  - Model to be estimated: $Y_{it} = \beta_1 X_{it} + \alpha_i + u_{it}$
  - Entity specific means over t: $\bar{Y}_i = \beta_1 \bar{X}_i + \alpha_i + \bar{u}_{it}$

- Within transformation ('demeaning' the data):

$$Y_{it} - \bar{Y}_i = \beta_1 (X_{it} - \bar{X}_i) + (u_{it} - \bar{u}_{it})$$

- This way **FE models control for all time invariant differences between the entities (by eliminating** α_i**)** , so the estimated coefficients are not biased because of unobserved time-invariant heterogeneity (*xtreg, fe* in STATA)

Comparing RE and FE

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- To use the FE model, you need significant **"within" variation** (across time) to estimate coefficients consistently
  - Not possible to estimate the effects of variables whose values do not change across time (because they are partialled out)
  - Even if there is little variation across time, the standard errors tend to be large (FE are not efficient)

- If you have a greater **"between" variation** (across entities), you would get better results using the RE estimator
  - Observed time-fixed variables can be included in the RE model
  - **However, keep in mind that RE models are inconsistent** if regressors are correlated with α_i

Comparing RE and FE

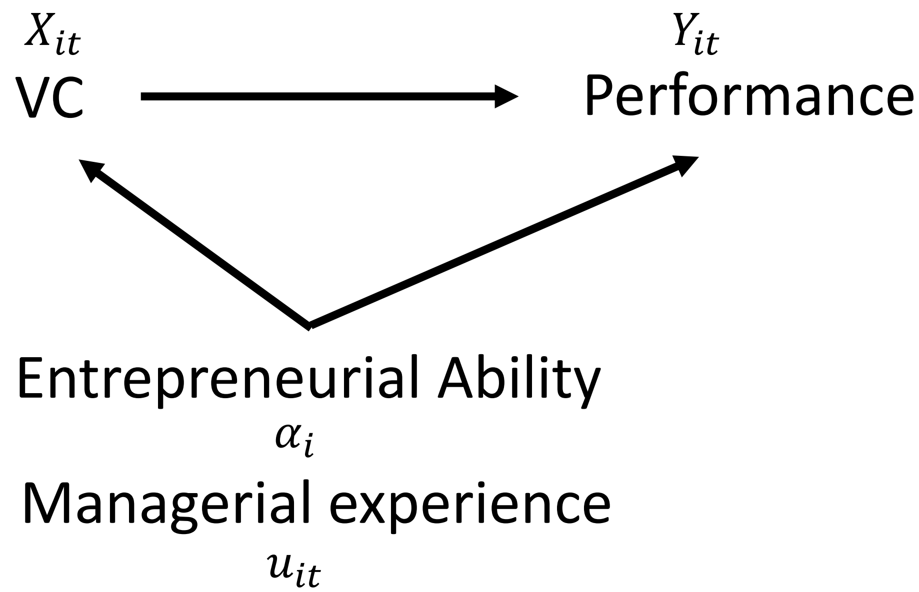
- **To decide between RE and FE you can run a Hausman test** (*hausman* in STATA)

- The null hypothesis is that the preferred model is RE vs. the alternative FE (Green, 2008):

$$H_0\colon \hat{\beta}_{FE} = \hat{\beta}_{RE}$$

- Use RE models if the null hypothesis is not rejected:
  - Intuition: the FE estimates are consistent; if the RE estimates do not differ too much, one can use RE regression (because it is more efficient)

Limitations of FE



- **FE estimators do not allow to control for omitted variables that are not time-invariant,** so that a critical assumption is that the error term u_{it} must be uncorrelated with X_{it}

IV regression

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- **If there are good reasons to believe** that the error term u_{it} is correlated with X_{it}, we need to abandon the FE framework

- A solution is to apply **instrumental variables (IV) estimations** in order to cut correlations between the error term and independent variables (*xtivreg, fe* or *re* in STATA)

- To conduct IV estimations, we need to have instrumental variables that are:
  - Uncorrelated with the error term
  - Sufficiently strongly correlated with X_{it}

Dynamic panel data models

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- AR(1) model with individual specific effects:

$$Y_{it} = \gamma Y_{it-1} + \alpha_i + u_{it}$$

- Here, by construction Y_{it-1} is correlated with α_i and u_{it-1}. Check:

$$Y_{it-1} = \gamma Y_{it-2} + \alpha_i + u_{it-1}$$

- FE estimator is now inconsistent (if short panel)
  - Instrumental Variable approach: **Arellano-Bond estimator (Generalized Method of Moments, GMM)** use data from other periods as instrumental variables

Some useful references

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Comprehensive panel texts

Baltagi, B.H. (1995, 2001), Econometric Analysis of Panel Data, 1st and 2nd editions, New York, John Wiley.

Hsiao, C. (1986, 2003), Analysis of Panel Data, 1st and 2nd editions, Cambridge, UK, Cambridge University Press.

More selective advanced panel texts

Arellano, M. (2003), Panel Data Econometrics, Oxford, Oxford University Press.

Lee, M.-J. (2002), Panel Data Econometrics: Methods-of-Moments and Limited Dependent Variables, San Diego, Academic Press.

Texts with several chapters on panel data

Cameron, A.C. and P.K. Trivedi (2005), Microeconometrics: Methods and Applications, New York, Cambridge University Press.

Greene, W.H. (2008), Econometric Analysis, sixth edition, Upper Saddle River, NJ, Prentice-Hall.

Wooldridge, J.M. (2002), Econometric Analysis of Cross Section and Panel Data, Cambridge, MA, MIT Press.

Some useful STATA commands

Panel summary: xtset; xtdescribe; xtsum; xtdata; xttab

RE model: xtreg, re

FE model: xtreg, fe

Hausman test: hausman

Static IV: xtivreg

Dynamic IV: xtabond; xtabond2 (user written command)

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Examples of applications in the context of Venture Capital

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Paper #1

Brander, J. A., Du, Q., & Hellmann, T. (2015). The effects of government-sponsored venture capital: international evidence. *Review of Finance*, *19*(2), 571-618

Aim of the paper

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- Many governments encourage the **provision of Venture Capital (VC)** finance to entrepreneurial ventures
  - **Government-sponsored VC funding**: financial resources channeled to entrepreneurial ventures
  - Waste of public money?

- This paper aims at providing **international empirical evidence on the effectiveness of government-sponsored VC funding**

- Main research question:
  - Does the activity of government-sponsored venture capitalists (GVCs) tend to **displace (crowd-out)** private venture capitalists (PVCs), or is GVC financing mainly **additional financing**?

Results

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- Two types of analyses:
  - Cross-sectional enterprise-level
  - **Panel data market-level**

- Positive evidence for the *additionality hypothesis*:
  - If GVC investment and PVC investment are both present in an enterprise, that enterprise tends to obtain more total VC funding
  - **Markets that receive more GVC funding also receive more funding overall and, strikingly, receive more PVC finance**

Panel data

- Data from 25 countries, 9 years, and 6 industries.

- The unit of the analysis is the **Market-Year observation**
  - Market is defined as the country-industry pair (25*6 = 150)
  - Each market is observed for 9 years
  - Total n. of observations = 150*9 = 1,350

- Estimation method:
  - FE regression
  - Dynamic panel specification

Key variables

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Panel C: Key variables defined at the market level

Variable	Obs	Mean	S.D.	Min	Max
Aggregate investment	1,350	134.45	691.36	0.00	19,010.71
Number of enterprises	1,350	16.15	61.43	0	1,624
Average investment	1,093	15.30	1.18	9.77	18.43
Average number of investors	1,093	1.50	0.72	1	7
Aggregate GVC investment	1,350	12.51	46.51	0.00	1,020.27
Aggregate PVC investment	1,350	121.94	650.64	0.00	17,990.46
Number of PVC enterprises	1,350	13.94	57.30	0	1,541
Average PVC investment	1,030	15.12	1.26	9.77	18.43
Average number of PVC investors	1,030	1.21	0.68	0.06	7

Results – FE

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Panel A: Combined investment				
Dependent variables	(1) Aggregate investment	(2) Number of enterprises	(3) Average investment	(4) Average number of investors
Aggregate GVC investment	0.364***	0.046***	0.015*	0.025***
	(0.052)	(0.003)	(0.008)	(0.006)
Fixed effects	Yes	Yes	Yes	Yes
Observations	1,350	1,350	1,093	1,093
R^2	0.369	0.618	0.345	0.283

Panel B: PVC investment				
Dependent variables	(1) Aggregate PVC investment	(2) Number of PVC enterprises	(3) Average PVC investment	(4) Average number of PVC investors
Aggregate GVC investment	0.218***	0.027***	–0.010	–0.004
	(0.043)	(0.003)	(0.007)	(0.006)
Fixed effects	Yes	Yes	Yes	Yes
Observations	1,350	1,350	1,030	1,030
R^2	0.277	0.541	0.373	0.302

Still endogeneity?

It is possible that an unobserved positive shock in the dependent variable might also cause an increase in the explanatory variable, inducing a correlation between market level PVC and GVC investment. The powerful fixed effects we use should control for many unobserved effects of this type, although ***some endogeneity might remain****. An additional correction is to use Arellano– Bond dynamic panel regressions.*

Results – Dynamic model

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Panel A: Combined investment				
Dependent variables	(1) Aggregate investment	(2) Number of enterprises	(3) Average investment	(4) Average number of investors
Aggregate GVC investment	0.359***	0.042***	0.007	0.016***
	(0.036)	(0.003)	(0.009)	(0.006)
Lagged dependent variable	–0.063	0.095***	–0.406***	–0.395***
	(0.039)	(0.034)	(0.052)	(0.049)
Fixed effects	Yes	Yes	Yes	Yes
Observations	1,200	1,200	840	840

Panel B: PVC investment				
Dependent variables	(1) Aggregate PVC investment	(2) Number of PVC enterprises	(3) Average PVC investment	(4) Average number of PVC investors
Aggregate GVC investment	0.206***	0.022***	–0.003	–0.007
	(0.036)	(0.003)	(0.010)	(0.006)
Lagged dependent variable	–0.050	0.106***	–0.482***	–0.432***
	(0.040)	(0.034)	(0.060)	(0.044)
Fixed effects	Yes	Yes	Yes	Yes
Observations	1,200	1,200	773	773

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Paper #2

Grilli, L., & Murtinu, S. (2014). Government, venture capital and the growth of European high-tech entrepreneurial firms. *Research Policy*, *43*(9), 1523-1543.

The paper in a nutshell

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- The idea is to assess the impact of government (GVC) and independent venture capital (IVC) on the **sales and employee growth** of **European high-tech entrepreneurial firms**

- Focus on **firm performance**

- **Key results:**
  - Positive effect of IVC and IVC-GVC syndicated coinvestments on firm sales growth (but not on employee growth)
  - Impact of GVC alone appears to be negligible

Data

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- **Source:** VICO dataset

- **Sample:**
  - Treated VC backed firms (239 GVC-backed , 538 IVC-backed, 126 co-investments)
  - Untreated firms as counterfactual (propensity score matching)

- **Unit of analysis:**
  - Firm-Year observations

Model specification

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The impact of GVC and IVC investments on firm growth is investigated through the estimation of a series of augmented Gibrat law panel data models (Evans, 1987) that are derived from the following model specification:

$$LnGrowth_{i,t} = \alpha_0 + \alpha_1 LnSize_{i,t-1} + \alpha_2 LnAge_{i,t} + \psi' VC_{i,t-1} + C_i + S_i + T_i + W_i + \varepsilon_{i,t}. \quad (1)$$

W are unobservable firm-specific factors; and ε are i.i.d. error terms

Econometric estimators

- **Pooled OLS** with controls for country, industry and time dummies
- **FE estimation**, which removes any potential concerns on the endogeneity of independent variables due to their alleged correlation with Wi
- To complement the FE estimation and account for the possible biases that are caused by both the dynamic specification and the unobserved time-varying heterogeneity, **GMM-SYS approach** (Blundell and Bond, 1998)

Results (a selection of)

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	Sales growth		
	OLS	FE	GMM-SYS ($t-3$; $t-4$)
Column	I	II	III
LnSize ($t-1$)	-0.1521^{***} (0.0213)	-0.6379^{***} (0.0466)	-0.2599^{***} (0.0716)
LnAge (t)	-0.2256^{***} (0.0507)	0.1051 (0.1774)	-0.1520 (0.1037)
IVC ($t-1$)	0.2159^{***} (0.0526)	0.3830^{***} (0.1186)	0.1948^{**} (0.0891)
Time dummies	Yes	Yes	Yes
Country dummies	Yes	–	Yes
Industry dummies	Yes	–	Yes
Obs.	2143	2143	2143
Groups	325	325	325
R^2	0.1879	0.1187	–
AR (1)	–	–	-3.96^{***}
AR (2)	–	–	0.06
Hansen test (p-value)	–	–	78.26 [76] (0.407)

Results (a selection of)

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	Employee growth		
	OLS	FE	GMM-SYS ($t-3$; $t-4$)
Column	V	VI	VII
LnSize ($t-1$)	−0.0539*** (0.0129)	−0.4219*** (0.0485)	−0.0551 (0.0379)
LnAge (t)	−0.1346*** (0.0205)	−0.0755 (0.0869)	−0.1230*** (0.0340)
IVC ($t-1$)	0.1009*** (0.0263)	0.0934 (0.0762)	−0.0129 (0.0592)
Time dummies	Yes	Yes	Yes
Country dummies	Yes	–	Yes
Industry dummies	Yes	–	Yes
Obs.	2375	2375	2375
Groups	342	342	342
R^2	0.1235	0.0378	–
AR (1)	–	–	−2.39**
AR (2)	–	–	0.05
Hansen test (p-value)	–	–	81.96 [74] (0.246)

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Paper #3

Bertoni, F., & Tykvová, T. (2015). Does governmental venture capital spur invention and innovation? Evidence from young European biotech companies. *Research Policy*, *44*(4), 925-935.

The paper in a nutshell

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- The paper explores whether and how **governmental venture capital** investors (GVCs) spur invention and innovation in young biotech companies in Europe

- **Dependent variables:**
  - Invention = patent stock
  - Innovation = citation-weighted patent stock

- **Key results**
  - GVCs, as stand-alone investors, have no impact on invention and innovation
  - GVCs boost the impact of independent venture capital investors (IVCs) on both invention and innovation

Data

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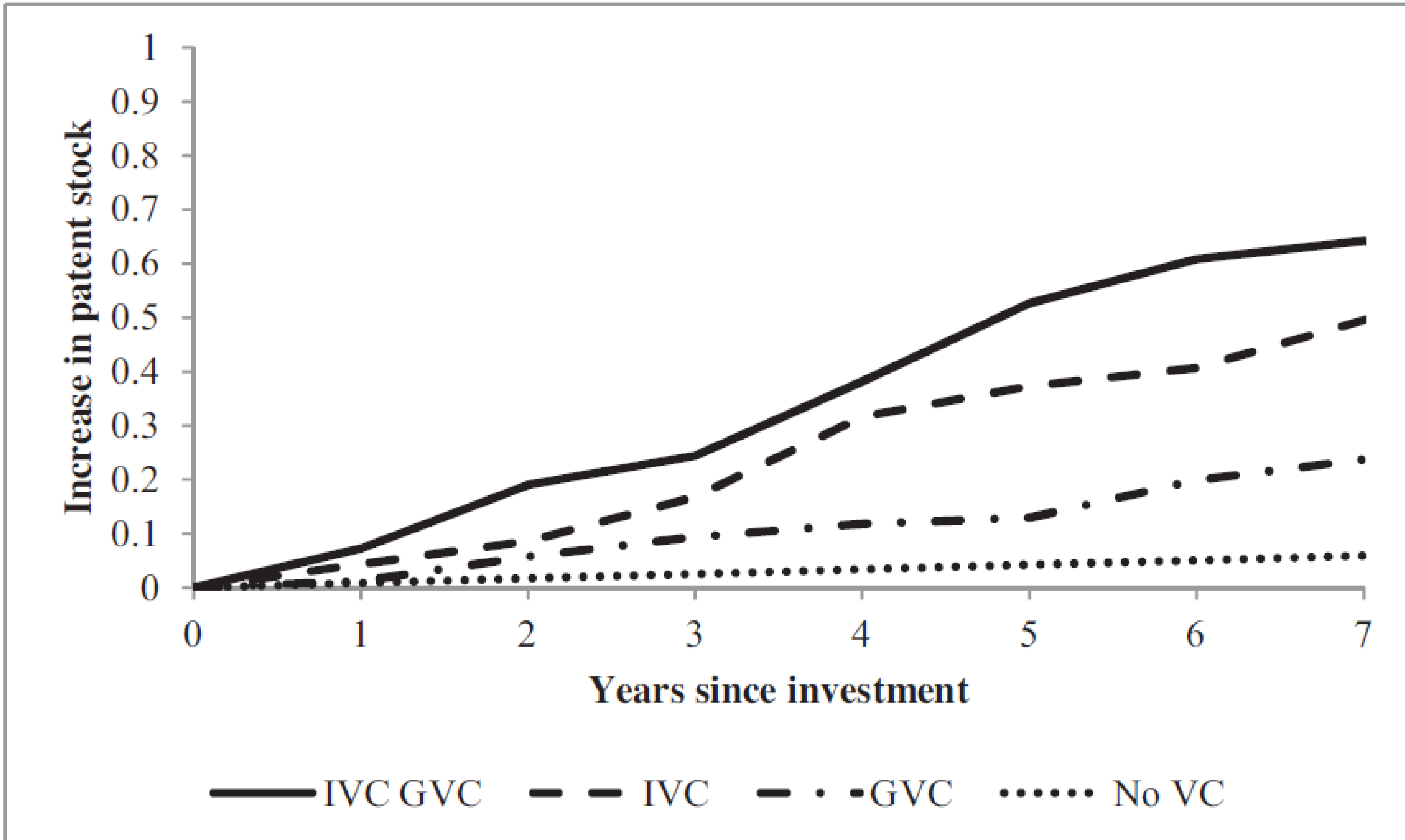
- Source: VICO dataset

- Sample
  - 125 treated VC backed firms (GVC-backed , IVC-backed, co-investments)
  - 540 untreated firms as counterfactual (propensity score matching)

- Unit of analysis:
  - Firm-Year observations

Descriptive evidence

Panel A: IVC,GVC and IVCGVC



Econometric estimators

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One very important challenge in estimating the effect of VC on any measure of firm performance is controlling unobserved heterogeneity. Specifically, results could be biased by unobservable company-specific characteristics that determine both VC financing and innovation (e.g., a better entrepreneurial team may be both better in attracting VCs and more inventive and innovative) and by the fact that VC is attracted by more innovative companies (e.g., Baum and Silverman, 2004; Engel and Keilbach, 2007; Bertoni et al., 2010b). To control for these time-invariant unobservable firm characteristics, we employ fixed-effects regressions (which also capture country-specific effects).

In order to control for time-variant unobserved heterogeneity we estimate Model 5 using a first-difference generalized method of moments (Arellano and Bond, 1991).

Results on invention

Table 4
Effect of VC on patent stoc

	Model 3 Fixed-effects	Model 5 Difference GMM
IVC	0.06**	0.20**
	(0.03)	(0.10)
GVC	-0.01	−0.04
	(0.03)	(0.07)
Other VC	-0.08*	−0.01
	(0.05)	(0.05)
Syndicate size	0.07***	0.05
	(0.02)	(0.04)
Age	0.01***	0.01***
	(0.00)	(0.00)
Age^2	−0.00***	−0.00***
	(0.00)	(0.00)
IVCGVC	0.27***	0.22**
	(0.04)	(0.10)
Lagged patent stock		0.47***
		(0.04)
Year dummies	Yes	Yes
H0: IVC = GVC	2.55	3.58*
N. observations	7891	6562
AR1		−6.65***
AR2		0.28
Hansen		367.47 [596]

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