Digital Technologies and Productivity: A Firm-level Investigation for Italy

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Digital Diffusion and Business Dynamism

- The diffusion of digital technologies has represented a major shift in the way individuals and firms operate
- Firms and markets are information processors and digital technologies reduce communication costs and costs for information search and processing (Goldfarb-Tucker, 2019)
- As shown by Calvino and Criscuolo (2019), digital diffusion should facilitate entry, upscaling and creative destruction, inducing a more dynamic business environment
- They find that digital intensive sectors are more dynamic than others but also that their business dynamism (entry, exit and job reallocation) has declined over the last 20 years, even faster than in other sectors (Gopinath et al., '17)

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Productivity Patterns and Digitalization

- Jorgenson et al ('08) and Bloom et al ('10) pointed to a post-95 rise in productivity driven by investments in IT in IT-using sectors, but it lasted until mid-2000s
- As stressed by Brynjolfsson, Rock and Syverson (2017) low productivity growth rates have been recorded over the past 10-15 years in almost all developed economies, especially the euro area. Labor productivity growth rates declined in the mid-2000s and have remained low since then
- Brynjolfsson et al (2017) also emphasize the progress of IT in many domains, from further technology advances in computer power to a large diffusion of innovative technologies, like cloud infrastructure, and to advances in artificial intelligence and machine learning
- The new Solow paradox: "we see transformative new technologies everywhere but in the productivity statistics"

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Literature Review

- At microeconomic level, a body of literature has established that firm adoption of digital technologies is conducive to higher productivity (Gal et al., 2019; Draca, Sadun and Van Reenen, 2006; Brynjolfsson and McElheran, 2016; Jin and McElheran, 2017; Brynjolfsson and Hitt, 2003)
- Some papers, however, reach a different conclusion. Acemoglu et al. (2014) provide (aggregate) evidence that the intensity of use of IT investments has no effect on productivity. Similarly, Bartelsman et al (2017) and DeStefano et al (2018) find no significant effect of firms' broadband access on their productivity (Gordon, '00;'03)

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Heterogeneity across Firms in the Productivity Gains

- A key finding in the literature is the high heterogeneity across firms in this effect: some firms enjoy large productivity gains from digital adoption while others do not
- This is in line with an increasing productivity dispersion between frontier and laggard firms detected by e.g. Andrews et al (2016)
- The degree of difference among firms in the impact of digital technologies on productivity reflects many factors
- Digital investments are complementary to skilled and specialized labor

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Complementary Investments: Human Resource Side (I)

- A reorganization process as well as managerial capital and innovation in human resource management are pre-conditions for adopting technologies and/or for enjoying productivity gains from their adoption (see e.g. Caroli and Van Reenen, 2002 and Tambe et al, 2012)
- Draca, Sadun and Van Reenen (2006) argue that ICTs are only the tip of the iceberg, as a successful realization of an ICT project requires a reorganization of the firm around the new technologies
- These reorganization costs may be interpreted as adjustment costs, but they can be large in the case of ICT
- In practice, these organizational complements refer to adaptation and in-depth refocusing of firms' organizational structure and practices (Caroli and Van Reenen, 2002)

Complementary Investments: Human Resource Side (II)

- Brynjolfsson and Hitt (2002) define these complementary innovation as "computer-enabled organizational investments" and argue that the contribution of IT to firm productivity hinges crucially on them
- Garicano (2010) emphasizes the relevance of complementarities between ICT and organizational design. Without organizational changes, the impact of ICT on productivity might be negligible
- Andrews, Nicoletti and Timiliotis (2018) provide evidence that capabilities to the complementary intangible investments, such as organizational capital, up-to-date managerial practices, innovative working arrangements, workers skills and an efficient allocation of human resources do affect adoption of digital technologies

What the paper does

- This paper seeks to investigate how digital technologies usage impinges on productivity
- We take a firm level perspective to control for the high degree of heterogeneity across firms which would otherwise be washed out in the aggregation process
- Our goal is to identify causal effects and establish the direct impact of firm's use of digital technology on its productivity
- To tackle problems of self-selection, endogeneity and reverse causation that may affect estimation of the relationship between digitalization and productivity, we employ the propensity score matching (PSM) approach combined with difference-in-difference (DiD)

The Data and the Measure of Digital Adoption

- We use three firm-level databases maintained and suitably integrated by Istat, the Italian Statistical Institute
- 1) the Permanent Census of enterprises; 2) the Statistical register of active enterprises (ASIA - Enterprises) and 3) the Frame SMS, a statistical register on economic accounts of Italian enterprises
- Importantly for our purposes, a Survey in the 2019 Permanent census of enterprises has a very detailed section on firms' use of digital technologies
- Among numerous questions, the Survey has asked firms to report whether, in the period 2016-2018, they have relied on each of 11 different digital technologies (Istat, 2020)

Measuring Firm's Digital Adoption

- Based on firms' responses to these questions, Istat developed a simple latent class model without covariates and identified four groups of firms in terms of their pattern of use of digital technologies. Firm membership in one of the classes was thus assigned (Istat, 2020)
- Relying on the in-depth analysis by Istat, we create two groups of firms: a) firms with a "non-systematic" or "constructive" attitude towards digitalization (those in the first two latent classes) and b) firms "experimenting innovative IT solutions" or "digitally mature" (those comprised in the other two classes)
- Firms in the latter group extensively adopt digital technologies, whilst those in the other group do not

The Empirical Methodology

- We consider digital adoption in the first group as a treatment, so that firms in that group are the treated firms, while those in the other group are the untreated firms
- Firms that rely extensively on digital technologies have characteristics that are likely to differ from those of firms that do not (self-selection into treatment)
- Hence, a difference in productivity between firms using digital technologies and those not using them does not correspond to the actual effect of digitalization
- We focus first on characteristics that may introduce heterogeneity in firms' propensity to use digital technologies. Among firms with these characteristics, some relied more on digital technologies while some did not

The Empirical Methodology

- The assignment of treatment is not random in our framework. Hence, we match firms that did rely extensively on digital technologies with their corresponding "twins" that, albeit showing similar characteristics, did not adopt these technologies (Angrist and Pischke, 2009)
- For each firm in the treated group we construct a "counterfactual" by focusing on *similar* firms in the untreated group
- The idea is to match firms with maximal similarity. Propensity score matching creates equivalent treatment and control groups in terms of confounding variables. From them we identify the impact of treatment (digitalization) on the outcome variable (productivity)

The Empirical Methodology

- The propensity score for a firm is the estimated conditional probability that it is included in the treatment group, P(T=1|X). Firms are matched according to their propensity to be treated and the approach therefore requires that there be firms with similar propensity scores in both groups
- Our first step is to estimate a probit model where the dependent variable is treatment (T) and the covariates are variables, X, evaluated before treatment, that are likely to influence the probability of being treated
- We estimate the propensity score from the probit model and use it for matching treated and untreated firms. Let us see the probit findings

Table: Determinants of Digital Adoption: the results of probit model

	Dep. variable: treatment	
	coeff.	se
Size (ref. under 10 employees)		
10-19	0.062***	(0.012)
20-49	0.262***	(0.012)
50-99	0.529***	(0.014)
100-249	0.748***	(0.016)
250 and more	1.148***	(0.021)
Age (ref. lowest quartile)		
2nd quartile	0.047***	(0.009)
3rd quartile	0.046***	(0.009)
Top quartile	0.043***	(0.010)
Labour cost per output unit (ref. lowest quartile)		
2nd quartile	-0.144***	(0.009)
3rd quartile	-0.275***	(0.010)
Top quartile	-0.438***	(0.010)
Service cost per output unit (ref. lowest quartile)		
2nd quartile	0.113***	(0.010)
3rd quartile	0.176***	(0.010)
Top quartile	0.245***	(0.010)
Sector by level of technology (ref. High-tech (Manufacturing))		
Medium high-tech (Manufacturing)	-0.284***	(0.029)
Medium low-tech (Manufacturing)	-0.359***	(0.029)
Low tech (Manufacturing)	-0.539***	(0.028)
Knowledge- intensive services	-0.140***	(0.029)
Less knowledge- intensive services	-0.521***	(0.028)
Other	-0.614***	(0.029)
Geographical Area (ref. North)		
Center	-0.130***	(0.009)
South	-0.165***	(0.009)
Constant	-0.256***	(0.031)
Pseudo R2	0.0643	
Nr. of obs.	166,988	

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The Determinants of Digital Adoption

- A marked digital adoption occurs more in larger firms. We consider six size classes and find that, compared to the lowest size class, the magnitude of the estimated coefficients progressively increase for higher size classes
- As for the sectors, compared to high-technology sectors in manufacturing, digital adoption is less likely in all other industries, both in manufacturing and in services
- Even in knowledge-intensive services, an extensive digital usage is less likely than in high-tech industries
- The effect of age is also positive as, compared to firms with age in the lowest quartile, older firms are more likely to rely on digital technologies

The Determinants of Digital Adoption

- Not surprisingly, compared to firms in the North of Italy, the other firms are less likely to adopt digital technologies
- Firms with a higher share of service purchases to the value of production are more likely to adopt digital technologies. Arguably, this expenditure may include services complementary to technology: training, consulting, testing and process engineering
- Firms with a higher share of labor costs to the value of production are less likely to adopt digital technologies. Arguably, this covariate somehow approximates how labor intensive the firm is and more labor-intensive firms are less likely to rely on digital technologies

The Empirical Methodology

- After estimating the probability that a firm adopts digitalization, we proceed with the match of treated to untreated units based on the propensity score
- Several matching algorithms are available: nearest-neighbor, radius and caliper, stratification, kernel
- Whilst they are all based on the distance between estimated propensity scores, they differ in how many units to match and how to do it
- We rely on the kernel-based matching, which associates to the outcome variable, Y_i, of a treated firm i a matched outcome given by a kernel-weighted average of outcomes of *all* untreated firms
- The weight to each untreated firm j is inversely proportional to distance in i's and j's propensity scores

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The Empirical Methodology

- An important condition for the PSM approach to be valid is that no systematic differences exist among firms in the treated and control groups in terms of unobserved characteristics that may affect the outcome variable
- This assumption is unlikely to hold as several unobserved factors may well introduce heterogeneity across firms in the adoption of digital technologies
- To tackle this issue, we use the time dimension of our data and resort to first difference for washing out unobserved sources of firms' heterogeneity in the outcome variable
- This is the difference-in-difference approach that computes the change in labor productivity between two periods of time (the first difference) and compares this variation between treated and untreated firms (the second difference)

The Empirical Methodology

- In practice, the effect of digitalization on productivity is calculated as follows:

  $$ATT = \frac{1}{N^T}\sum_{i=1}^{N^T}\left(\Delta \ln LP_i^T - \sum_{j=1}^{N^C} w_{ij}\Delta \ln LP_j^C\right),$$

  where ATT is the Average Treatment effect on the Treated. N^T and N^C are the number of treated and control firms. LP is labor productivity.
  $\sum_{j=1}^{N^C} w_{ij}\Delta \ln LP_j^C$ is the weighted average of (log of) productivity change for all untreated firms, with weights, w_{ij}, proportionally decreasing as the distance of the propensity score from the treated firm, i, increases

The Effect of Digital Adoption on the (log of) Productivity Variation (2015-2018): (1) Gross Output per Worker

	(1)	(2)
Models	PSM DID	PSM DID
ATT	0.030***	0.027***
	(0.004)	(0.004)
Observations	166,982	166,982

Robust standard errors in parentheses
Standard errors are clustered at firm level
*** p<0.01, ** p<0.05, * p<0.1
(1) Epanechnikov kernel
(2) Gaussian kernel

The Effect of Digital Adoption on the (log of) Productivity Variation (2015-2018): (2) Value added per Worker

	(1)	(2)
Models	PSM DID	PSM DID
ATT	0.009**	0.011***
	(0.004)	(0.003)
Observations	196,092	196,012

Robust standard errors in parentheses

Standard errors are clustered at firm level

*** p<0.01, ** p<0.05, * p<0.1

(1) Epanechnikov kernel

(2) Gaussian kernel

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Assessing the matching quality: (1) Balancing Test

	Mean		%bias	t-test	
	Treated	Control		t	p-value >t
Size (ref. under 10 employees)					
10-19	0.2256	0.23111	-1.2	-2.12	0.034**
20-49	0.3654	0.36526	0	0.05	0.964
50-99	0.15375	0.14913	1.4	2.08	0.037**
100-249	0.10651	0.10496	0.6	0.82	0.414
250 and more	0.07089	0.06906	0.9	1.16	0.245
Age (ref. lowest quartile)					
2nd quartile	0.24788	0.24922	-0.3	-0.5	0.616
3rd quartile	0.24708	0.24647	0.1	0.23	0.82
Top quartile	0.25548	0.24994	1.3	2.06	0.039**
Labour cost per unit (ref. lowest quartile)					
2nd quartile	0.27528	0.27183	0.8	1.25	0.21
3rd quartile	0.23821	0.23599	0.5	0.84	0.399
Top quartile	0.19411	0.19896	-1.2	-1.97	0.048**
Service cost per output unit (ref. lowest quartile)					
2nd quartile	0.23909	0.23875	0.1	0.13	0.896
3rd quartile	0.26756	0.26593	0.4	0.6	0.55
Top quartile	0.2958	0.29473	0.2	0.38	0.702
Sector by level of technology (ref. High-tech (Manufacturing))					
Medium high-tech (Manufacturing)	0.13288	0.1278	1.6	2.44	0.015**
Medium low-tech (Manufacturing)	0.14301	0.14224	0.2	0.35	0.723
Low tech (Manufacturing)	0.13227	0.12932	0.9	1.41	0.157
Knowledge- intensive services	0.17492	0.17679	-0.5	-0.8	0.426
Less knowledge- intensive service	0.32068	0.32773	-1.5	-2.44	0.015**
Other	0.07349	0.07377	-0.1	-0.17	0.862
Geographical Area (ref. North)					
Center	0.16873	0.17031	-0.4	-0.68	0.497
South	0.14771	0.15294	-1.4	-2.36	0.018**
Pseudo R2	0.000				
p > chi2	0.168				
B	3.3				
R	1.09				

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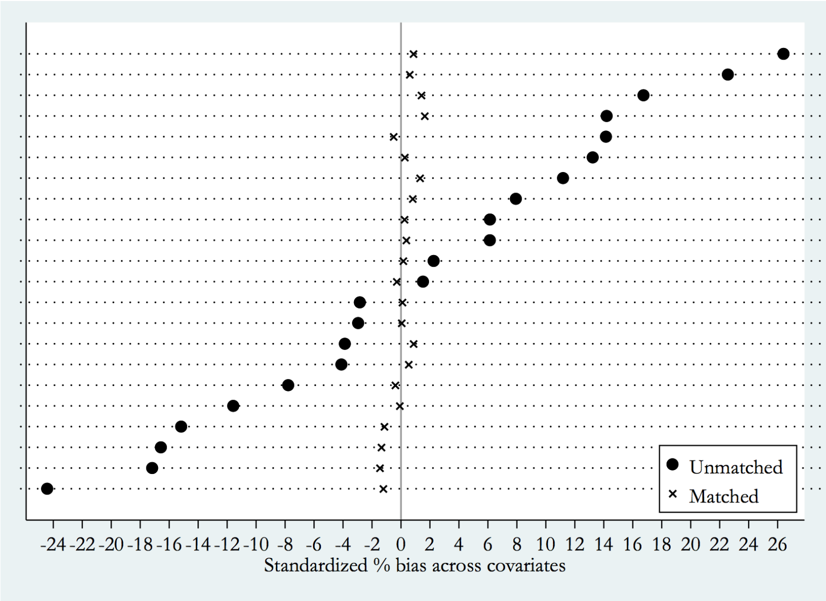
Assessing the matching quality: (2) standardised bias



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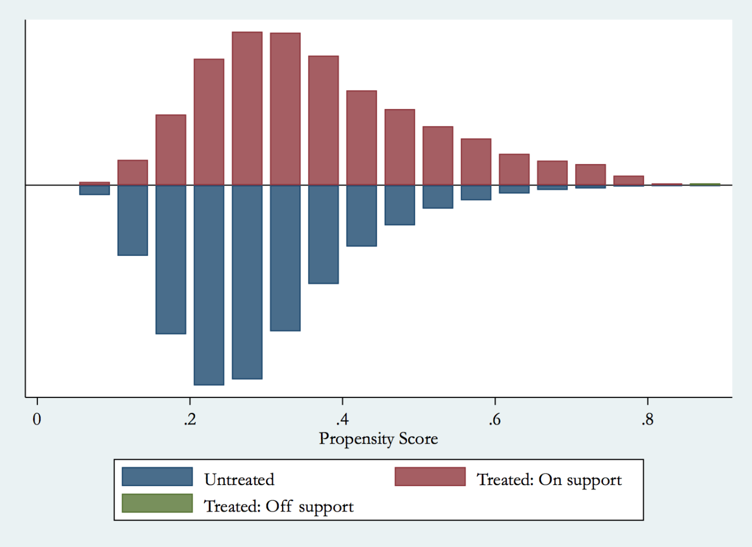
Assessing the matching quality: (3) Common support



A Sensitivity Check:
Enlarging the Group of Untreated (Control) Firms

Models	(1) Baseline	(2) Larger Control Group
ATT	0.030**	0.037***
	(0.004)	(0.004)
Observations	166,982	200,074

Robust standard errors in parentheses
Standard errors are clustered at firm level
*** p<0.01, ** p<0.05, * p<0.1
Labor productivity is gross output per worker
The matching algorithm is the Epanechnikov kernel

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Heterogeneity in the productivity effect: 1) Manufacturing vs. Service Firms

	(1)	(2)
Models	Manufacturing	Services
ATT	0.031***	0.028***
	(0.0005)	(0.007)
Observations	64,472	86,380

Robust standard errors in parentheses
Standard errors are clustered at firm level
*** p<0.01, ** p<0.05, * p<0.1
Labor productivity is gross output per worker
The matching algorithm is the Epanechnikov kernel

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Heterogeneity in the productivity effect: 2) Smaller vs. Larger Firms

	(1)	(2)
Models	Smaller Firms	Larger Firms
ATT	0.044***	0.023***
	(0.009)	(0.007)
Observations	83,465	83,498

The threshold criterion for splitting the sample
according to size is the median of the number of workers
Robust standard errors in parentheses
Standard errors are clustered at firm level
*** p<0.01, ** p<0.05, * p<0.1
Labor productivity is gross output per worker
The matching algorithm is the Epanechnikov kernel

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Heterogeneity in the productivity effect: 3) Younger vs. Older Firms

	(1)	(2)
Models	Younger Firms	Older Firms
ATT	0.051***	0.020***
	(0.009)	(0.006)
Observations	80,755	86,216

The threshold criterion for splitting the sample according to age is the median
Robust standard errors in parentheses
Standard errors are clustered at firm level
*** $p<0.01$, ** $p<0.05$, * $p<0.1$
Labor productivity is gross output per worker
The matching algorithm is the Epanechnikov kernel

Main Findings and Concluding Remarks

- We uncover some evidence on the characteristics of firms that introduce a degree of difference across them in the degree of adoption of digital technologies
- We estimate that digital technologies allow the "treated" firms to enjoy a rate of variation of labor productivity, between 2015 and 2018, which is about 3 percentage points higher, on average, than that of firms with low digital adoption
- We also find that the estimated productivity gains from digital technologies are larger for
    - firms in manufacturing
    - smaller firms
    - younger firms
- Delving into human resource practices as a source of specificity in the effect of digitalization on productivity will be the task of our future research jointly with Istat researchers