Knowledge Spillovers, ICT and Productivity Growth

Carol Corrado, (The Conference Board), New York
Jonathan Haskel, (Imperial College, CEPR and IZA), London
Cecilia Jona-Lasinio, (ISTAT and LLEE), Rome

3rd SEEK Conference
April 25-26, 2013,
ZEW, Mannheim, Germany

Motivation

- The literature on intangible capital expands the core concept of business investment in national accounts by treating much business spending on "intangibles" as investment (e.g., see Corrado, Hulten, and Sichel 2005).
- When this expanded view of investment is included in a sources-of-growth analysis, intangible capital is found to account for 1/5 to 1/3 of labour productivity growth in the market sector of the US and EU economies (Corrado, Haskel, Jona-Lasinio, and Iommi (2012); Corrado, Hulten, and Sichel (2009); Marrano, Haskel, and Wallis (2009))
- The contribution in Japan and many EU countries has been found to be lower (Fukao, Hamagata, Miyagawa, and Tonogi 2009 and van Ark, Hao, Corrado, and Hulten 2009).

The CHS Framework

Broad category	Type of Investment
Computerized Information	• Software • Databases
Innovative Property	• R&D • Mineral exploration • Entertainment and artistic originals • Other new product development costs (e.g. design)
Economic Competencies	• Branding and reputation (mkt. research and advertising) • Firm-specific human capital (training) • Organizational capital (business process investment)

Source: Corrado, Hulten and Sichel, 2005, 2009 and Carol Corrado, OECD/MIT presentation, NAS, December, 2012

Motivation

- The cross-country sources-of-growth literature (Corrado *et al.* (2012), van Ark *et al.* (2009)) that includes intangible capital also finds a strong correlation between
  - the contribution of intangible capital deepening to a country's growth in output per hour and
  - the country's rate of growth of multi-factor productivity (MFP)
- Are these effects mostly driven by R&D, (Griliches 1998)?
  - Private R&D stocks tend to be no more than 20 to 25 percent of total private net stocks of intangibles.
- What about ICT, Intangible capital and their synergies?
- Are they the main drivers of growth to look at?

Motivation

- Microeconomic evidence demonstrates that the link from ICT to productivity growth is complex, requiring for example co-investments in training and organizational change, and that simply adopting ICT does not provide automatic competitive advantage (e.g., Bresnahan, Brynjolfsson, and Hitt 2002; Brynjolfsson, Hitt, and Yang 2002)
- Findings in the macro literature are more limited (due to the heretofore lack of comprehensive data on intangibles) but nonetheless suggest that returns to ICT and productivity growth are higher once the complementary role of intangibles is accounted for (e.g., Basu, Fernald, Oulton, and Srinivasian 2003)

Aim

- We investigate the channels through which intangible capital affects productivity growth, testing:
  - Direct and indirect contributions from intangibles to productivity growth.
  - Interactions with other variables in influencing Average Labour Productivity (ALP) growth.

Main findings

- We uncover two mechanisms that reinforce the growth accounting evidence that intangible capital is an important driver of productivity growth.
  - The estimated output elasticity of intangible capital exceeds its factor share after controlling for endogeneity, consistent with an externality - driven relationship between intangibles and productivity.
  - Spillovers from intangibles are robustly identified
  - Positive contributions to productivity growth from interaction effects between intangible capital and industry ICT intensity

The Model

- Suppose that industry value added in country c, industry i and time t, $Q_{c,i,t}$ can be written as:

$$\Delta lnQ_{c,i,t} = \epsilon^{L}_{c,i,t}\Delta lnL_{c,i,t} + \epsilon^{K}_{c,i,t}\Delta lnK_{c,i,t} + \\ + \epsilon^{R}_{c,i,t}\Delta lnR_{c,i,t} + \Delta lnA_{c,i,t}$$

- First order condition

$$\epsilon^{X}_{c,i,t} = s^{X}_{c,i,t} + d^{X}_{c,i,t}$$

$$X = L, K, R$$

- which says that output elasticities equal factor shares plus d, where d is any deviation of elasticities from factor shares due to e.g. spillovers, omitted variables (Stiroh, 2003).

The Model

- Denoting conventional value added (in which intangibles are treated as intermediates) as Q, we can then write:

$$\Delta lnQ_{c,i,t} = (1 - s^R_{c,i,t})\Delta lnQ_{c,i,t} + s^R_{c,i,t}\Delta lnN_{c,i,t}$$

where N is real intangible investment and we have approximated the share of intangible investment costs in nominal Q as s^R, the share of intangible rental payments in nominal Q.

$$\begin{aligned}\Delta lnQ_{c,i,t} &= (1 - s^R_{c,i,t})\Delta lnV_{c,i,t} + s^R_{c,i,t}\Delta lnN_{c,i,t} \\ &= (s^L_{c,i,t} + d^L_{c,i,t})\Delta lnL_{c,i,t} + (s^K_{c,i,t} + d^K_{c,i,t})\Delta lnK_{i,c,t} + \\ &+ (s^R_{c,i,t} + d^R_{c,i,t})\Delta lnR_{i,c,t} + \Delta lnA_{i,c,t}\end{aligned}$$

The Model

- The Divisia index (Caves, Christensen and Diewert (1982)) for $\Delta lnTFP$ can be written as :

$$\Delta lnTFP_{c,i,t} = d^{L}_{c,i,t}\Delta lnL_{c,i,t} + d^{K}_{c,i,t}\Delta lnK_{c,i,t} + \\ + d^{R}_{c,i,t}\Delta lnR_{c,i,t} + \Delta lnA_{c,i,t}$$

where

$$\Delta lnTFP_{c,i,t} = s^{L}_{c,i,t}\Delta lnL_{c,i,t} + s^{K}_{c,i,t}\Delta lnK_{c,i,t} + s^{R}_{c,i,t}\Delta lnR_{c,i,t}$$

- Therefore, a regression of $\Delta lnTFP$ on the inputs recovers the spillover terms.

From theory to growth empirics: our strategy

- Standard production function style regressions:
  - Direct effects (ALP - Intangible capital - Other K)
  - Indirect effects (TFP - Intangible capital - Other K)
- Complementarities between Intangibles and ICT:
  - Difference-in-Difference approach (Rajan and Zingales, (1998))

Data

- Intangible assets
  - INTAN-Invest Database
    (Corrado, Haskel, Jona-Lasinio, Iommi (2012))
    www.intan – invest.net
- Production function variables
  - EUKLEMS, OECD STAN and WIOD Databases
- Geographical ,Time and Industry Coverage:
  - AT, DK, FI, FR, GE, IT, NL, SP, SWE, UK, US
  - Yearly data: 1995 - 2007
  - Industries: 26 (NACE Rev. 2 Classification)

Empirical specification: (1)

- Production function regression: *direct effects*

$$\Delta ln(V_{c,t}/L_{c,t}) = \alpha_1 \Delta ln(K_{c,t}^{ICT}/L_{c,t}) + \alpha_2 \Delta ln(K_{c,t}^{NonICT}/L_{c,t}) + \\ + \alpha_3 \Delta ln(K_{c,t}^{INTAN}/L_{c,t}) + \alpha_4 \Delta lnL_{c,t} + \\ + \lambda_c + \lambda_t + \nu_{ct}$$

- Production function regression: *indirect effects*

$$\Delta lnTFP_{c,t} = \beta_1 \Delta ln(K_{c,t}^{ICT}/L_{c,t}) + \beta_2 \Delta ln(K_{c,t}^{NonICT}/L_{c,t}) + \\ + \beta_3 \Delta ln(R_{c,t}/L_{c,t}) + \beta_4 \Delta lnL_{c,t} + \\ + \lambda_c + \lambda_t + \nu_{ct}$$

Empirical specification: (2)

- Production function regression: *complementary effects*

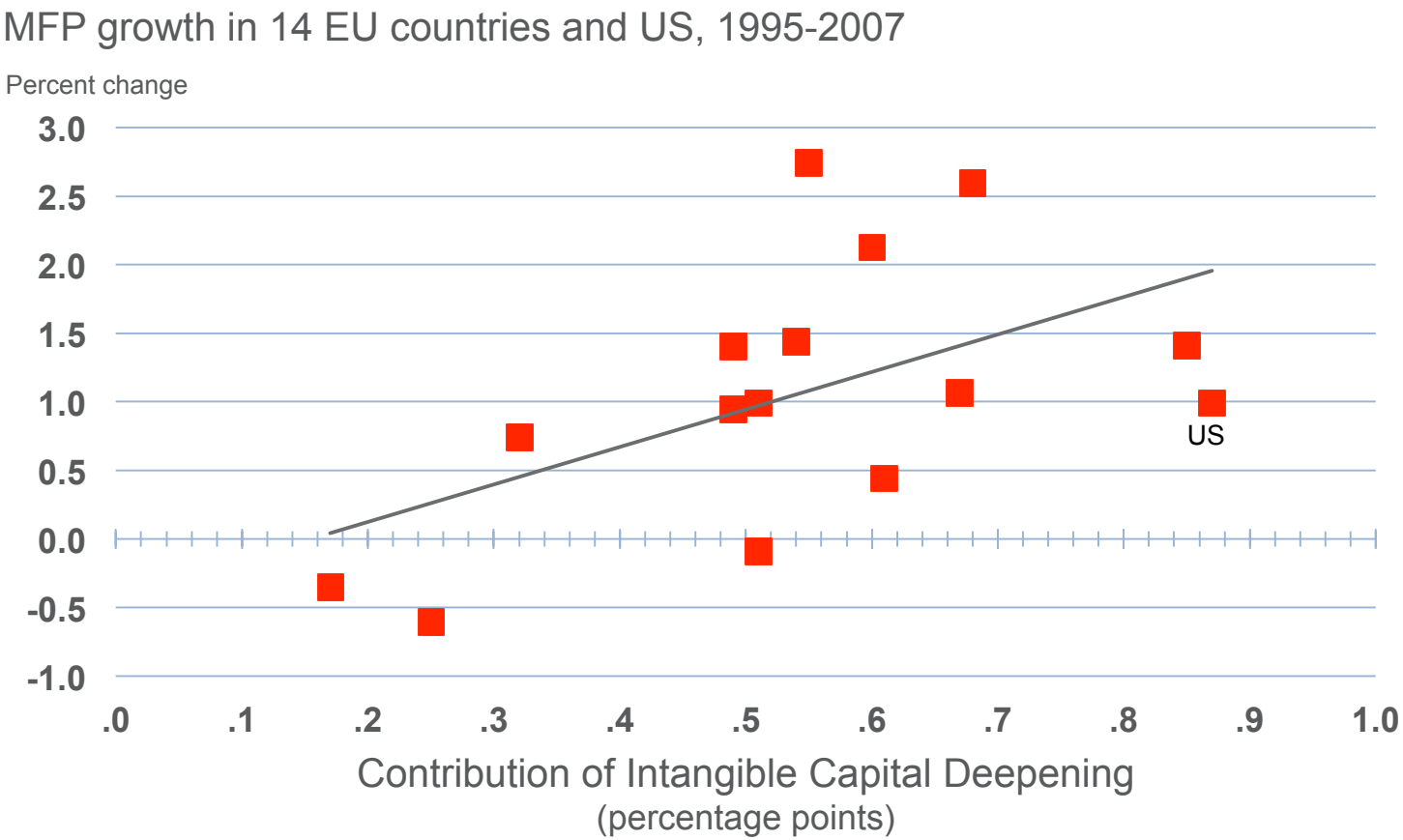
$$\begin{aligned}\Delta ln(V_{i,c,t}/L_{i,c,t}) = {} & \gamma_1 \Delta ln(K^{ICT}_{i,c,t}/L_{i,c,t}) + \\ & + \gamma_2 \Delta ln(K^{NonICT}_{i,c,t}/L_{i,c,t}) + \\ & + \gamma_3 \Delta ln(R_{i,c,t}/L_{i,c,t}) + \\ & + \gamma_4 \Delta ln(R_{i,c,t}/L_{i,c,t}) * \overline{(K^{ICT}/L)_{i,c}} + \\ & + \gamma_5 \overline{(K^{ICT}/L)_{i,c}} + \\ & + \lambda_i + \lambda_c + \lambda_t + \nu_{i,c,t}\end{aligned}$$

Empirical specification

- **Elasticities vs factor shares ($\alpha_3 > s^{INTAN}$)** and $\beta_3 > 0$: Spillovers and other effects
- **Improvement effect ($\gamma_4 > 0$)**: faster growth in more technological (ICT) advanced industries is associated with increasing intangible capital accumulation.
- **Endogeneity of intangible capital**:
  - Country level data on most of intangibles
  - IV estimates
  - Country, time and industry fixed effects

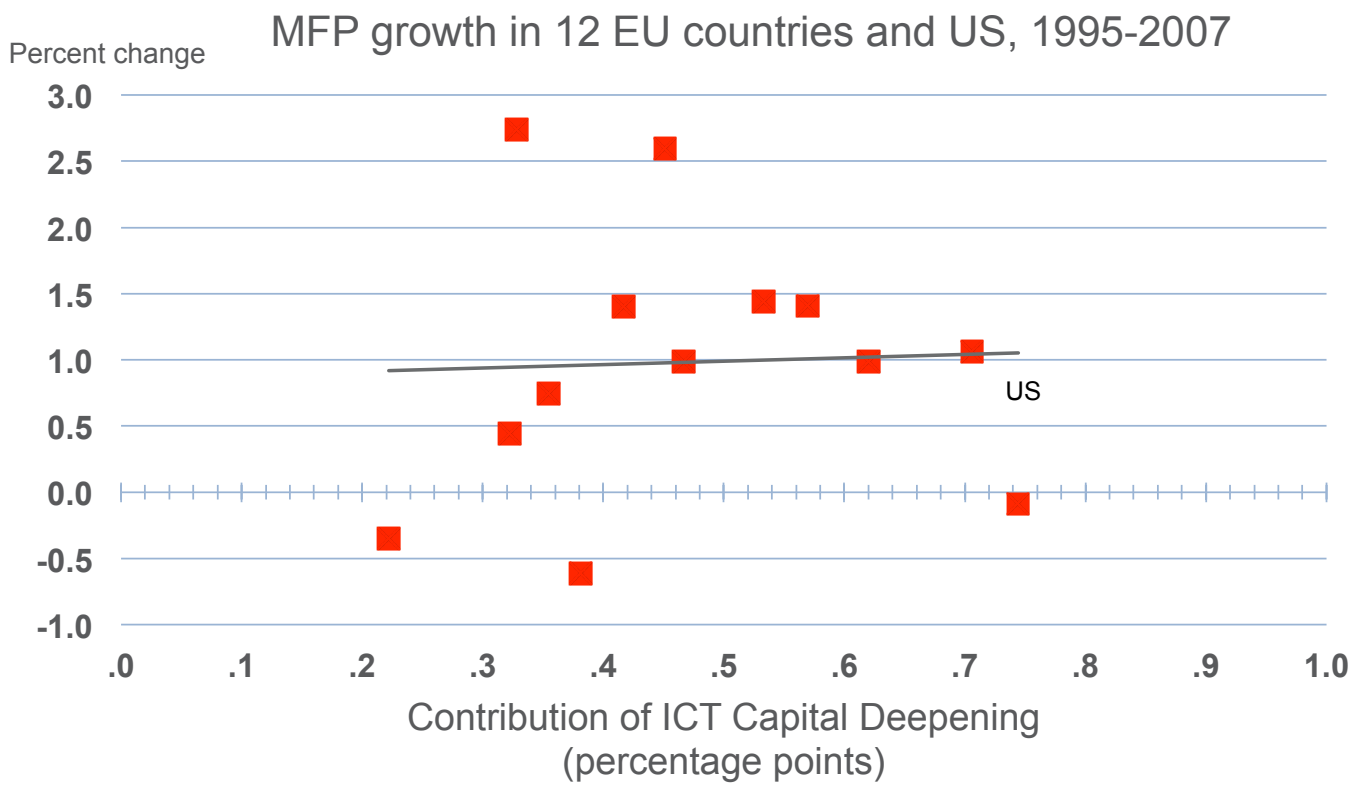
Intangibles vs MFP

Spurious correlation or spillover to intangible investment?



ICT vs MFP

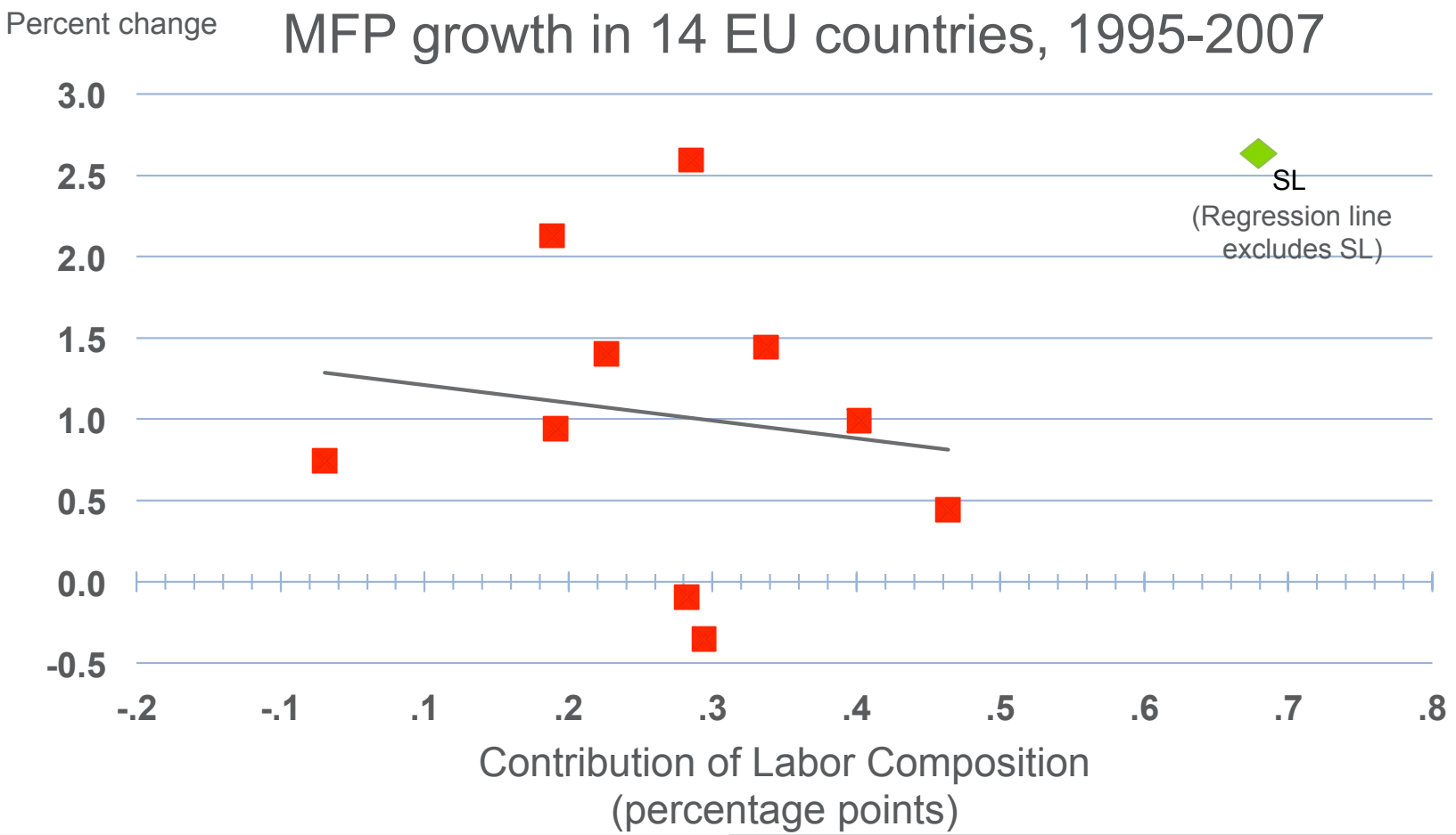
No hint of spillovers to ICT capital deepening



Source: Corrado, Haskel, and Jona-Lasinio, January 10, 2013.

L- quality vs MFP

… nor for labor composition ("quality").



Empirical results

Table 1 - Production function - benchmark estimates: testing for intangible capital effects
(Country level estimates)

	(1)	(2)	(3)	(4)
	Labour productivity			
	va not adj	va adj	va not adj	va adj
VARIABLES	**OLS**		**IV**	
[ΔNICT]	0.480**	0.362***	0.232***	0.151***
	(0.0714)	(0.0607)	(0.0883)	(0.0556)
[ΔICT]	0.0891**	0.0578*	0.179***	0.0797**
	(0.0385)	(0.0308)	(0.0567)	(0.0343)
[ΔTOTINTG]		**0.244*** **		**0.560*** **
		(0.0660)		**(0.0543)**
Observations	108	108	90	90
R-squared	0.730	0.824	0.299	0.655
F-test(12, 68) for first-stage regressions of endogenous regressors				
[ΔICT]			13.021	12.41
P-value			[0.000]	[0.0000]
[ΔNICT]			21.160	23.08
P-value			[0.000]	[0.0000]
[ΔTOTINTG]				45.40
P-value				[0.0000]
Hansen - J statistics [P-value]			0.001	0.021
C - statistics [P-value]			0.163	0.317

Robust (heteroskedasticity - adjusted) standard errors are reported in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1
The dependent variable is the delta log of value added per labour services at the country-time level.
Row 1 indicates where DlnVA has been adjusted and is not adjusted for intangibles.
All capital variables are per labour services.
All specifications include country and time fixed effects (coefficients not reported).
Columns 1-6 are estimated by OLS, columns 7 to 12 by instrumental variables: ICT, NICT, INTG Lserv.
List of instruments:NICT_US, NICT_LAG, ICT_LAG, INTG_US, INTLAG, Lquality_lag

Empirical results

Table 2 - Factor shares vs elasticities: looking for non-traditional effects of ICT and Intangibles

	Time period 1995-2007				
	A	B	C	D	E
	av rate of growth	factor shares	estimated coeff	ga contribution	estimated contribution
Intangible K	4.3	0.11	0.57	0.46	2.45
ICT K	4.0	0.05	0.11	0.20	0.44
NICT K	3.4	0.26	0.16	0.87	0.54

$$\epsilon^k{}_{c,t} = s^k{}_{c,t} + d^k{}_{c,t}$$

- Potential links between intangible capital and TFP are:
  - Spillovers
  - Omitted variables
  - Measurement errors
  - Reverse causality

Empirical results

Table 2 - TFP benchmark estimates: testing for spillovers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	TFP							
	va not adj	va not adj	va adj	va adj	va not adj	va not adj	va adj	va adj
VARIABLES	OLS				IV			
[ΔNICT]	-0.523***	0.326***	-0.00819	0.0449	-0.0898	-0.104	-0.0112	-0.0543
	(0.101)	(0.103)	(0.113)	(0.111)	(0.0628)	(0.0903)	(0.0657)	(0.153)
[ΔICT]	-0.242***	-0.184***	0.0260	0.0779	-0.183***	-0.0366	0.00389	0.00921
	(0.0486)	(0.0561)	(0.0545)	(0.0580)	(0.0369)	(0.0369)	(0.0499)	(0.0985)
[ΔTOTINTG]			0.155	**0.249****			0.0328	**0.388****
			(0.131)	**(0.119)**			(0.0867)	**(0.157)**
[ΔL]	-1.247***		-0.418**		-1.436***		-0.206	
	(0.164)		(0.204)		(0.153)		(0.127)	
[ΔL]_lag		-0.0449		**0.636*****		-0.895***		**0.593*****
		(0.147)		**(0.167)**		(0.138)		**(0.152)**
Observations	108	99	108	99	90	90	90	99
R-squared	0.789	0.729	0.547	0.557	0.715	0.542	0.454	0.544
F-test for first-stage regressions of endogenous regressors								
[ΔNICT] P-value					20.8 [0.000]	19.2 [0.000]	26.4 [0.000]	28.2 [0.000]
[ΔICT] P-value					9.6 [0.000]	10.8 [0.000]	9.7 [0.000]	12.36 [0.000]
[ΔTOTINTG] P-value							24.1 [0.000]	17.9 [0.000]
[ΔL] P-value					9.9 [0.000]		10.5 [0.000]	
Hansen - J statistics [overidentification test of all instruments (P-value)]					0.0095	0.0145	0.0323	0.002

Robust (heteroskedasticity - adjusted) standard errors are reported in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1
The dependent variable is the delta ln of total factor productivity for the market sector at the country-time level.
Row 1 indicates where DlnTFP has been adjusted and is not adjusted for intangibles.
All capital variables are per labour services.
All regressors are current period, except row 5 where DlnL is lagged one period.
All specifications include country and time fixed effects (coefficients not reported).
Columns 1-4 are estimated by OLS, columns 5 to 9 by instrumental variables: ICT, NICT, INTG Lserv.
List of instruments:NICT_US, NICT_LAG, ICT_LAG, INTG_US, INTLAG, Lquality_lag

Empirical results

Table 3 - Testing for spillovers: ICT, INTANGIBLES and R&D

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	TFP					
	va non adj			va adj		
	OLS					
[ΔTOTINTG-N]	-0.140	-0.142		0.153*	0.145*	
	(0.0915)	(0.0909)		(0.0801)	(0.0787)	
[ΔRD]	0.185		0.638**	0.290		0.236
	(0.256)		(0.300)	(0.224)		(0.220)
[ΔICT]	-0.196***	-0.191***	-0.192**	0.0838	0.0935*	0.110*
	(0.0654)	(0.0647)	(0.0756)	(0.0573)	(0.0560)	(0.0555)
[ΔNICT]	0.337***	0.380***	-0.233	0.0553	0.119	0.160
	(0.126)	(0.121)	(0.143)	(0.110)	(0.105)	(0.105)
[ΔL]_lag	-0.0441	-0.0394	-0.0675	0.624***	0.613***	0.641***
	(0.191)	(0.189)	(0.223)	(0.167)	(0.164)	(0.164)
Observations	99	99	99	99	99	99
R-squared	0.738	0.739	0.670	0.566	0.566	0.567

Robust (heteroskedasticity - adjusted) standard errors are reported in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1

The dependent variable is the delta ln of total factor productivity for the market sector at the country-time level.

All regressors are current period, except row 5 where DlnL is lagged one period.

All specifications include country and time fixed effects (coefficients not reported).

All capital variables are per labour services.

Empirical Results: Intangibles-ICT interactions

Table 3 - Production function and ICT- Intangibles interactions
(Country - Industry level estimates)

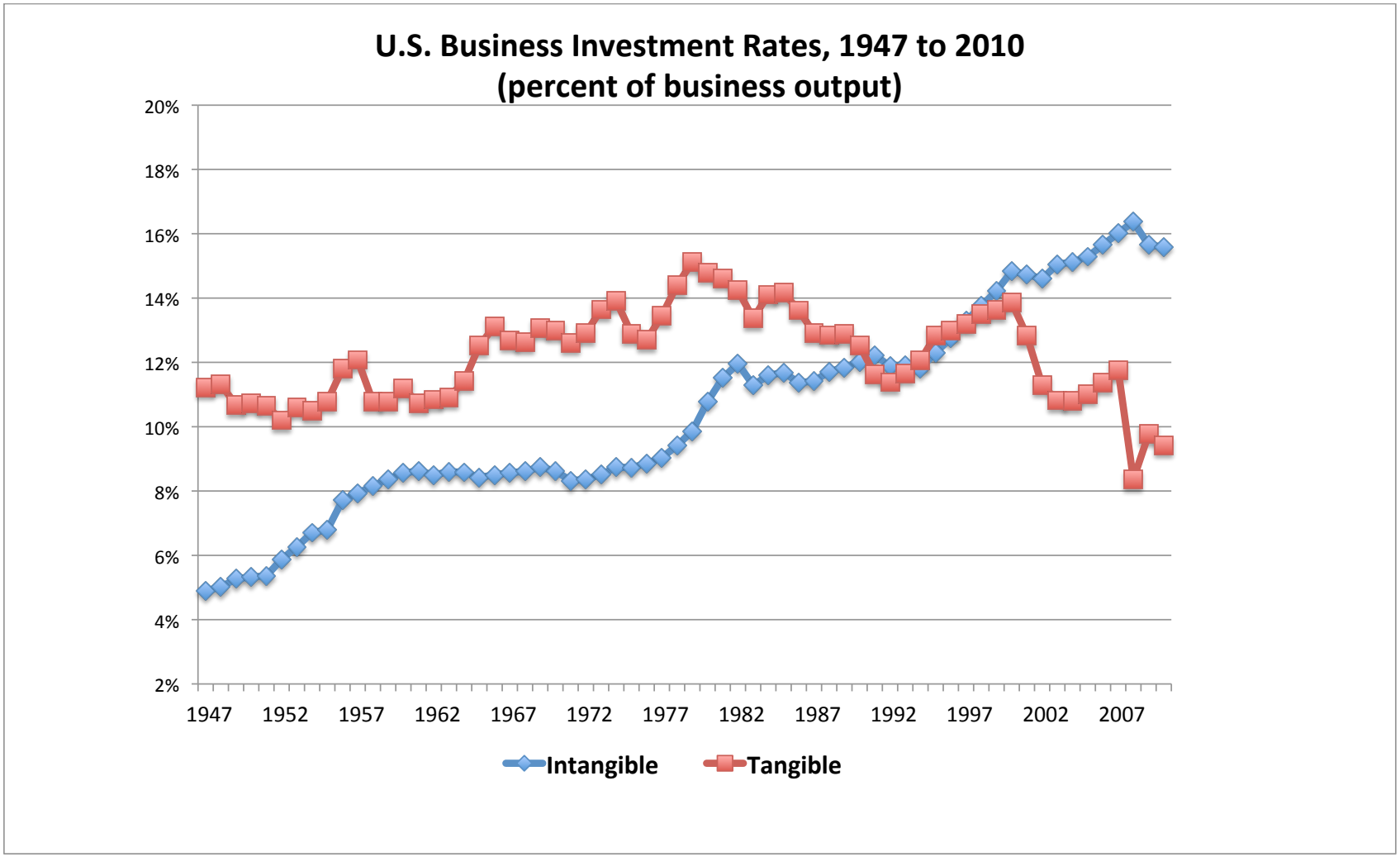
	(1)	(2)	(3)	(4)	(5)	(6)
			ICT-C		ICT-US	
VARIABLES	**OLS**	**IV**	**OLS**	**IV**	**OLS**	**IV**
[ΔTOTINTG]	**0.476*** (0.0293)**	**0.477*** (0.0723)**				
[ICTXΔTOTINTG]			**0.108*** (0.0263)**	**0.145*** (0.0451)**		
[ICT USXΔTOTINTG]					**0.0938*** (0.0282)**	**0.136*** (0.0431)**
Observations	2,268	1,890	2,268	2,079	2,268	2,079
R-squared	0.382	0.283	0.390	0.291	0.388	0.293

The dependent variable is the delta log of value added per labour services at the country-industry-time level.
All variables are per labour services
The interactions in cls 3-4 are the product of ICT (including software) intensity at the country-industry level and the accumulation of total intangible capital.
The interactions in cls 5-6 are the product of the US ICT intensity at the industry level and the accumulation of total intangible capital.
All specifications include country and time fixed effects (coefficients not reported).
Robust (heteroskedasticity - adjusted) standard errors are reported in parentheses below the coefficients.
Instrumented variables: ICT, NICT, INTG
List of instruments:NICT_US, NICT_LAG, ICT_LAG, INTG_US, INTLAG

Summary results

- Significant direct effects of intangibles on productivity growth.
- The estimated output elasticity of intangible capital exceeds its factor share, consistent with spillovers and other effects to intangibles.
- When intangibles are capitalized they have to be included in the output (adjusted TFP).
- If output is adjusted then spillovers from intangibles, ICT and L (but not from R&D) are identified.
- ICT amplifies the productivity returns of intangible capital.

Intangibles: a long story to tell



Back up slides

Empirical results

Table 1 - Production function - benchmark estimates: testing for intangible capital effects
(Country level estimates)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Labour productivity						Labour productivity					
	va not adj	va not adj	va not adj	va adj	va adj	va adj	va not adj	va not adj	va not adj	va adj	va adj	va adj
VARIABLES	OLS						IV					
[ΔNICT]	0.480**	0.196**	0.473***	0.362***	0.123**	0.359***	0.232***	0.173**	0.221**	0.151***	0.126***	0.143**
	(0.0714)	(0.0768)	(0.0758)	(0.0607)	(0.0605)	(0.0641)	(0.0883)	(0.0725)	(0.0875)	(0.0556)	(0.0489)	(0.0559)
[ΔICT]	0.0891**	0.0498	0.0881**	0.0578*	0.0304	0.0565*	0.179***	0.0940**	0.180***	0.0797**	0.0452	0.0790**
	(0.0385)	(0.0370)	(0.0414)	(0.0308)	(0.0291)	(0.0334)	(0.0567)	(0.0430)	(0.0539)	(0.0343)	(0.0279)	(0.0316)
[ΔTOTINTG]				**0.244*** **	**0.224*** **	**0.240*** **				**0.560*** **	**0.468*** **	**0.550*** **
				(0.0660)	**(0.0701)**	**(0.0685)**				**(0.0543)**	**(0.0550)**	**(0.0529)**
[ΔL]		-0.947***			-0.711***			-0.605***			-0.390***	
		(0.125)			(0.109)			(0.0662)			(0.0675)	
[ΔL]_lag			-0.0301			-0.0133			-0.280***			-0.231***
			(0.123)			(0.0964)			(0.0839)			(0.0723)
Observations	108	108	99	108	108	99	90	90	90	90	90	90
R-squared	0.730	0.758	0.731	0.824	0.848	0.825	0.299	0.521	0.358	0.655	0.756	0.756
F-test(12, 68) for first-stage regressions of endogenous regressors												
[ΔICT]							13.021	11.346	11.191	12.41	11.69	14.05
P-value							[0.000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
[ΔNICT]							21.160	21.494	20.763	23.08	24.22	24.02
P-value							[0.000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
[ΔTOTINTG]										45.40	33.74	47.93
P-value										[0.0000]	[0.0000]	[0.0000]
Hansen - J statistics [overidentification test of all instruments (P-value)]							0.001	0.003	0.007	0.021	0.016	0.014
C - statistics [exogeneity/orthogonality of selected instruments (P-value)]							0.163	0.817	0.128	0.317	0.113	0.210

Robust (heteroskedasticity - adjusted) standard errors are reported in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1
The dependent variable is the delta log of value added per labour services at the country-time level.
Row 1 indicates where DlnVA has been adjusted and is not adjusted for intangibles.
All capital variables are per labour services.
All specifications include country and time fixed effects (coefficients not reported).
Columns 1-6 are estimated by OLS, columns 7 to 12 by instrumental variables: ICT, NICT, INTG Lserv.
List of instruments:NICT_US, NICT_LAG, ICT_LAG, INTG_US, INTLAG, Lquality_lag

Empirical Results: Intangibles-ICT interactions

Table 4 - Intangible capital accumulation, ICT intensity and industry productivity growth

VARIABLES	ICT-C	ICT US	ICT-C	ICT US	ICT-C	ICT US	ICT-C	ICT-US	ICT-C	ICT US
	OLS		OLS		OLS		OLS		OLS	
R&D [ICTxΔR&D]	0.0661***	0.0664***								
	(0.0218)	(0.0239)								
Training [ICTxΔTRN]			0.0960***	0.0785***						
			(0.0253)	(0.0268)						
Organizational capital (P) [ICTxΔORP]					0.0393**	0.0304*				
					(0.0154)	(0.0167)				
Organizational capital (o) [ICTxΔORO]							0.0531***	0.0507***		
							(0.0178)	(0.0195)		
Architectural and engeneering design [ICTxΔAED]									0.104***	0.0946***
									(0.0259)	(0.0277)
Observations	2268	2268	2268	2268	2268	2268	2268	2268	2268	2268
R-squared	0.368	0.378	0.392	0.390	0.341	0.339	0.343	0.342	0.362	0.36

The dependent variable is the delta log of value added per labour services at the country-industry-time level.
The interactions in the odd cls are the product of ICT (including software) intensity at the country-industry level and the accumulation of each intangible asset.
The interactions in the even colums are the product of the US ICT intensity at the industry level and the accumulation of intangible assets.
All specifications also include country fixed effects, industry fixed effects and time fixed effects (coefficients not reported).
Robust (heteroskedasticity - adjusted) standard errors are reported in parentheses below the coefficients.
Instrumented variables: ICT, NICT, INTG, INTG*ICT
List of instruments:NICT_US, NICT_LAG, ICT_LAG, INTG_US, INTLAG
Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1