Knowledge Capital and U.S. State-level Differences in Labor Productivity

Sabrina Wulff Pabilonia, Ph.D.
U.S. Bureau of Labor Statistics

Susan Fleck, Ph.D.
U.S. Bureau of Labor Statistics

ASSA meetings

January 4, 2020

Disclaimer: All views expressed in this paper are those of the authors and do not necessarily reflect the views or policies of the U.S. Bureau of Labor Statistics.

Overview

- There is substantial variation in U.S. state-level labor productivity levels and growth rates
- This paper considers the extent to which variation in state-level knowledge capital can explain these differences
- Knowledge capital is measured by completed years of schooling and achievement test scores

Overview

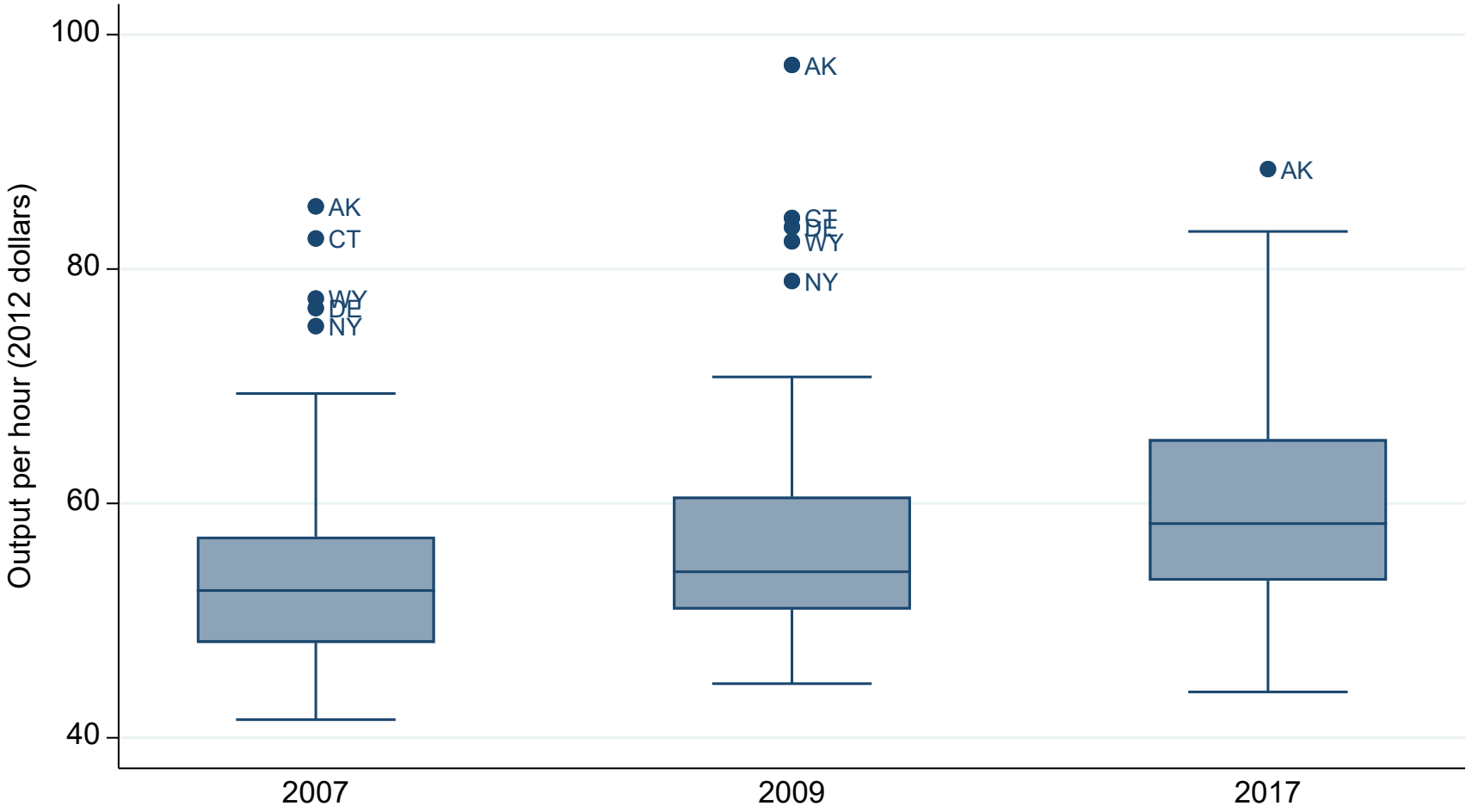
- The paper extends the work of Hanushek, Ruhose and Woessmann (HRW) in the following ways:
  - GDP per capita is replaced by labor productivity
    - Output per hour worked accounts for time available for production
    - BLS published experimental state-level labor productivity estimates in June 2019
  - Examine the private nonfarm sector rather than the total economy
    - Aligns better with official U.S. nonfarm business labor productivity
  - The time horizon is extended from 2007 to 2017

BLS State-level Labor Productivity

Newly-published experimental dataset (June 2019)
www.bls.gov/lpc/state-productivity.htm

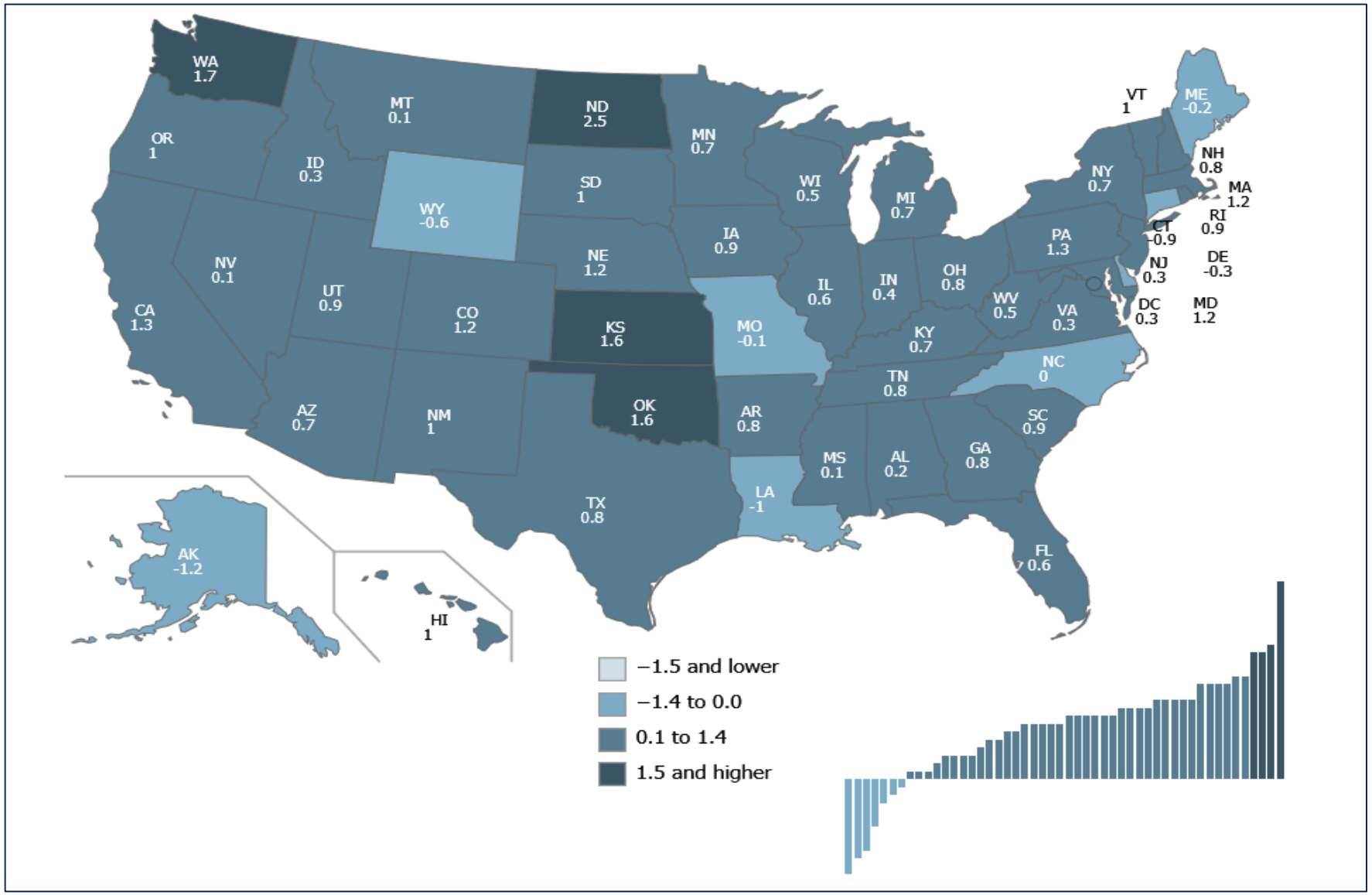
- Annual data for 50 U.S. States and the District of Columbia (2007-2017)
- Output – Bureau of Economic Analysis (BEA) data on real GDP by state for all private industries, excluding the farm sector, private households, and owner-occupied housing
- Hours – Bureau of Labor Statistics (BLS) data on hours worked
  - Wage and salary employees (establishment data)
  - Unincorporated self-employed (household data)
  - Unpaid family workers (household data)

Distribution of Output per Hour Worked of U.S. States



Source: U.S. Bureau of Labor Statistics (2019)

Average Annual Productivity Growth, 2009–2017



Source: U.S. Bureau of Labor Statistics (2019)

Knowledge Capital at the State Level

HRW measure knowledge capital per worker, *h*, as follows:

$$h = e^{rS+wT}$$

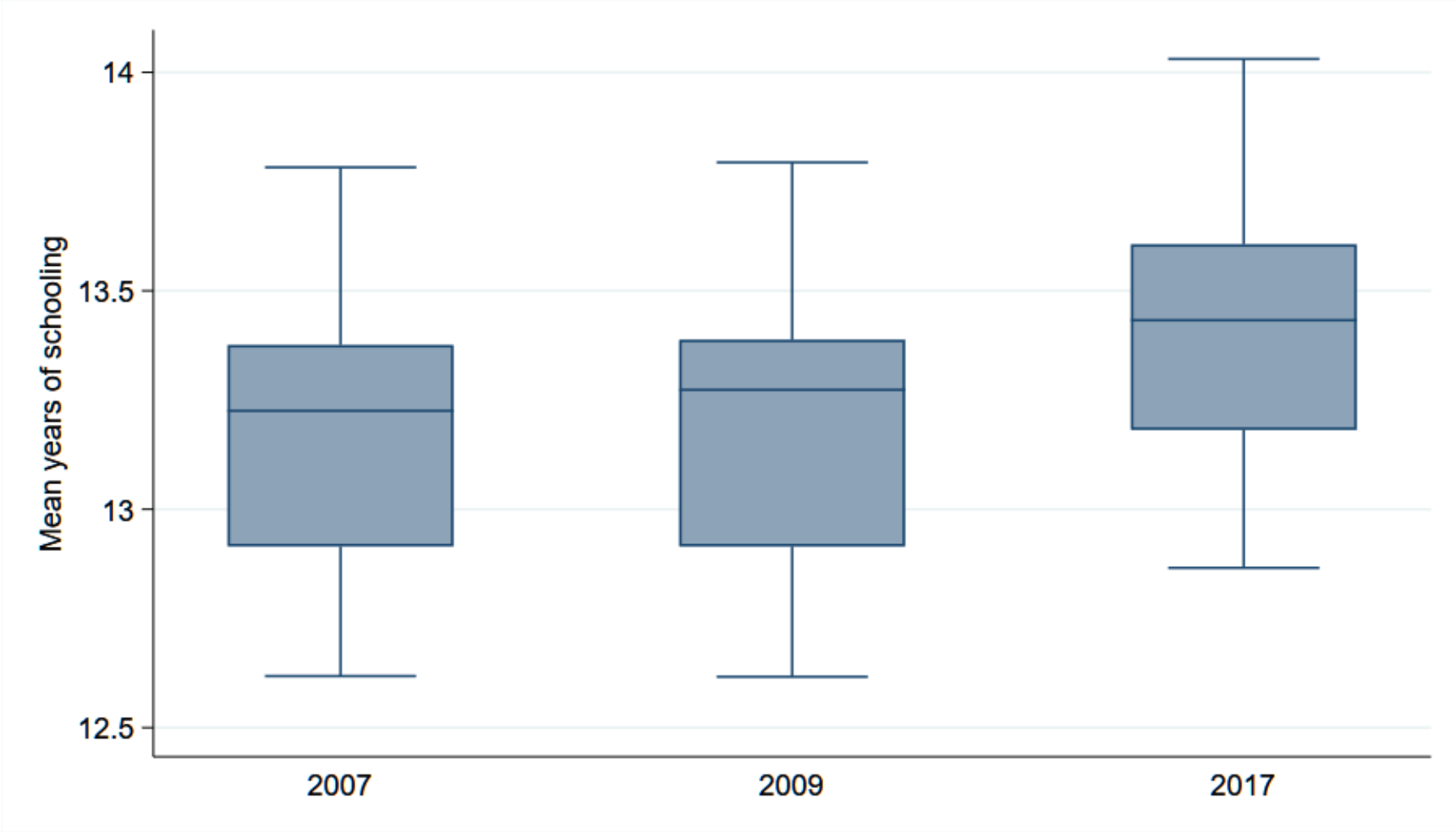
where

- *S* is the average completed years of schooling for working-aged population,
- *T* is the average test score for working-aged population
- *r* is the return per year of schooling ($r = 0.08$)
- *w* is the return per standard deviation in test scores ($w = 0.17$)

Years of schooling data are constructed from the American Community Survey (ACS) (20-65 year olds).

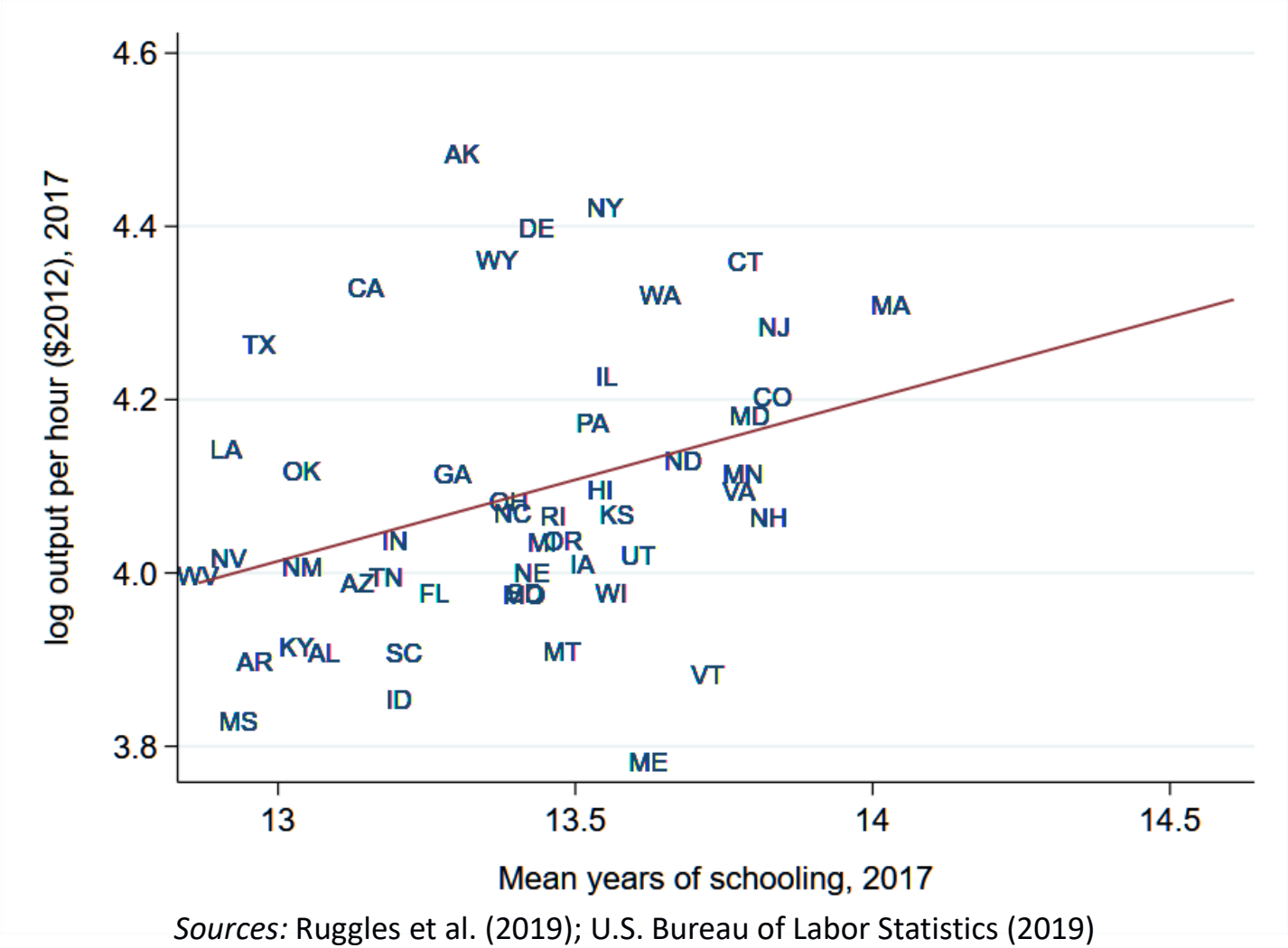
Test scores are taken directly from HRW. They are based primarily on eighth grade mathematics achievement test scores (adjustments for immigrants and migration between states).

Distribution of Average Years of Schooling of U.S. States



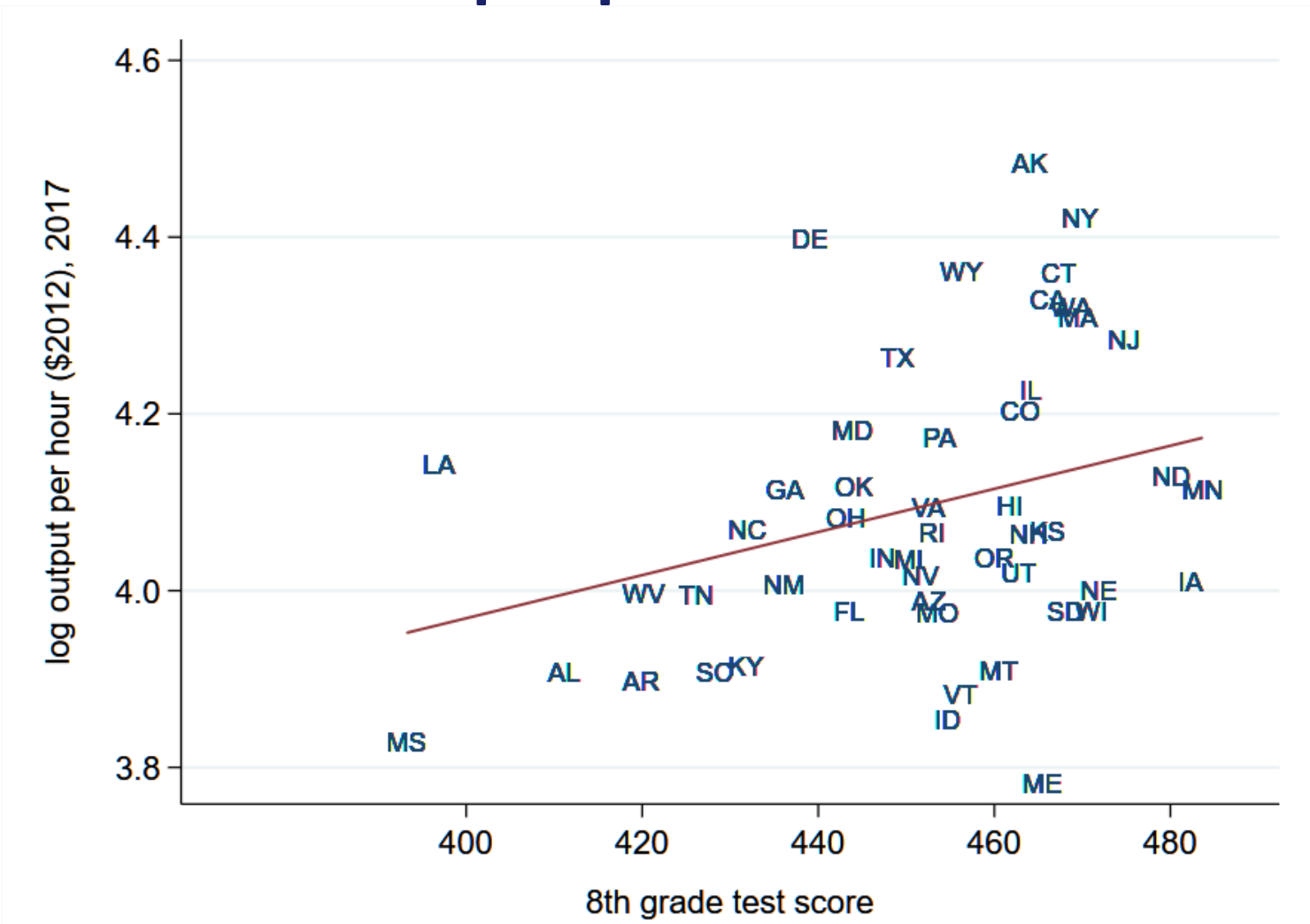
Source: Ruggles et al. (2019)

Years of Schooling and Output per Hour across U.S. States, 2017



Sources: Ruggles et al. (2019); U.S. Bureau of Labor Statistics (2019)

Cognitive Skills and Output per Hour across U.S. States, 2017



Sources: Hanushek, Ruhose, Woessman (2017b); U.S. Bureau of Labor Statistics (2019)

The Share of Labor Productivity Variance Attributable to Knowledge Capital

- The framework is based upon the following aggregate Cobb-Douglas production function:

$$Y = (hL)^{1-\alpha} K^{\alpha} A^{\lambda},$$

where *Y* is output; *h* is aggregate knowledge capital per worker; *L* is hours worked; *K* is physical capital stock; and A^{λ} represents multi-factor productivity. Assuming $\lambda = 1 - \alpha$ (i.e. Harrod-neutral productivity), then labor productivity can be written as folllows

$$\frac{Y}{L} \equiv y = h \left(\frac{k}{y}\right)^{\alpha/(1-\alpha)} A,$$

where $k \equiv \frac{K}{L}$ is the capital-labor ratio.

The Share of Labor Productivity Variance Attributable to Knowledge Capital

- Development Accounting Decomposition:

$$\underbrace{\frac{cov(ln(y),ln(h))}{var(ln(y))}}_{\text{knowledge capital}} + \underbrace{\frac{cov\left(ln(y),ln\left(\left(\frac{k}{y}\right)^{\alpha/(1-\alpha)}\right)\right)}{var(ln(y))}}_{\text{physical capital}} + \underbrace{\frac{cov(ln(y),ln(A))}{var(ln(y))}}_{\text{Total factor productivity}} = 1$$

The Share of Labor Productivity Variance Attributable to Knowledge Capital

- Development Accounting Decomposition:

$$\underbrace{\frac{cov(ln(y),ln(h))}{var(ln(y))}}_{\text{knowledge capital}} + \underbrace{\frac{cov\left(ln(y),ln\left(\left(\frac{k}{y}\right)^{\alpha/(1-\alpha)}\right)\right)}{var(ln(y))}}_{\text{physical capital}} + \underbrace{\frac{cov(ln(y),ln(A))}{var(ln(y))}}_{\text{Total factor productivity}} = 1$$

Development Accounting Results

Productivity measures:	N	Year	Covariance measure: Total knowledge capital	Covariance measure: Test scores	Covariance measure: Years of Schooling
Sample excludes those enrolled in school					
GDP per capita (HRW published 2017b)	47	2007	0.228	0.135	0.093
			(0.044)	(0.028)	(0.023)
Output per hour worked	47	2007	0.099	0.057	0.042
			(0.063)	(0.040)	(0.028)

Components of GDP per Capita

$$\frac{GDP}{Population} = \frac{GDP}{Output_{PNF}} * \frac{Output_{PNF}}{Hours\ worked_{PNF}} * \frac{Hours\ worked_{PNF}}{Employed\ persons_{PNF}} *$$

$$\frac{Employed\ persons_{PNF}}{Employed\ persons} * \frac{Employed\ persons}{Population}$$

Components of GDP per Capita

$$\underbrace{\frac{GDP}{Population}}_{y_0} = \underbrace{\frac{GDP}{Output_{PNF}}}_{y_1} * \underbrace{\frac{Output_{PNF}}{Hours\ worked_{PNF}}}_{y_2} * \underbrace{\frac{Hours\ worked_{PNF}}{Employed\ persons_{PNF}}}_{y_3}$$

$$* \underbrace{\frac{Employed\ persons_{PNF}}{Employed\ persons}}_{y_4} * \underbrace{\frac{Employed\ persons}{Population}}_{y_5}$$

Covariance Decomposition

$$\frac{\mathrm{cov}(\mathrm{lny}_0, \mathrm{lnh})}{\mathrm{var}(\mathrm{lny}_0)} = \frac{\mathrm{var}(\mathrm{lny}_1)}{\mathrm{var}(\mathrm{lny}_0)}\frac{\mathrm{cov}(\mathrm{lny}_1, \mathrm{lnh})}{\mathrm{var}(\mathrm{lny}_1)} + \frac{\mathrm{var}(\mathrm{lny}_2)}{\mathrm{var}(\mathrm{lny}_0)}\frac{\mathrm{cov}(\mathrm{lny}_2, \mathrm{lnh})}{\mathrm{var}(\mathrm{lny}_2)}$$

$$+ \frac{\mathrm{var}(\mathrm{lny}_3)}{\mathrm{var}(\mathrm{lny}_0)}\frac{\mathrm{cov}(\mathrm{lny}_3, \mathrm{lnh})}{\mathrm{var}(\mathrm{lny}_3)} + \frac{\mathrm{var}(\mathrm{lny}_4)}{\mathrm{var}(\mathrm{lny}_0)}\frac{\mathrm{cov}(\mathrm{lny}_4, \mathrm{lnh})}{\mathrm{var}(\mathrm{lny}_4)}$$

$$+ \frac{\mathrm{var}(\mathrm{lny}_5)}{\mathrm{var}(\mathrm{lny}_0)}\frac{\mathrm{cov}(\mathrm{lny}_5, \mathrm{lnh})}{\mathrm{var}(\mathrm{lny}_5)}$$

Covariance Decomposition

$$\frac{\operatorname{cov}(\ln y_0, \ln h)}{\underbrace{\operatorname{var}(\ln y_0)}_{0.224}} = \underbrace{\frac{\operatorname{var}(\ln y_1)}{\operatorname{var}(\ln y_0)}}_{0.102} \underbrace{\frac{\operatorname{cov}(\ln y_1, \ln h)}{\operatorname{var}(\ln y_1)}}_{0.189} + \underbrace{\frac{\operatorname{var}(\ln y_2)}{\operatorname{var}(\ln y_0)}}_{0.932} \underbrace{\frac{\operatorname{cov}(\ln y_2, \ln h)}{\operatorname{var}(\ln y_2)}}_{0.099}$$

$$+ \underbrace{\frac{\operatorname{var}(\ln y_3)}{\operatorname{var}(\ln y_0)}}_{0.036} \underbrace{\frac{\operatorname{cov}(\ln y_3, \ln h)}{\operatorname{var}(\ln y_3)}}_{-1.422} + \underbrace{\frac{\operatorname{var}(\ln y_4)}{\operatorname{var}(\ln y_0)}}_{0.069} \frac{\operatorname{cov}(\ln y_4, \ln h)}{\operatorname{v}\underbrace{\operatorname{ar}(\ln y_4)}_{0.223}} + \underbrace{\frac{\operatorname{var}(\ln y_5)}{\operatorname{var}(\ln y_0)}}_{0.256} \underbrace{\frac{\operatorname{cov}(\ln y_5, \ln h)}{\operatorname{var}(\ln y_5)}}_{0.574}$$

Covariance Decomposition

$$\frac{\operatorname{cov}(\ln y_0, \ln h)}{\underbrace{\operatorname{var}(\ln y_0)}_{0.224}} = \underbrace{\frac{\operatorname{var}(\ln y_1)}{\operatorname{var}(\ln y_0)}}_{0.102} \underbrace{\frac{\operatorname{cov}(\ln y_1, \ln h)}{\operatorname{var}(\ln y_1)}}_{0.189} + \underbrace{\frac{\operatorname{var}(\ln y_2)}{\operatorname{var}(\ln y_0)}}_{0.932} \underbrace{\frac{\operatorname{cov}(\ln y_2, \ln h)}{\operatorname{var}(\ln y_2)}}_{0.099}$$

$$+ \underbrace{\frac{\operatorname{var}(\ln y_3)}{\operatorname{var}(\ln y_0)}}_{0.036} \underbrace{\frac{\operatorname{cov}(\ln y_3, \ln h)}{\operatorname{var}(\ln y_3)}}_{-1.422} + \underbrace{\frac{\operatorname{var}(\ln y_4)}{\operatorname{var}(\ln y_0)}}_{0.069} \underbrace{\frac{\operatorname{cov}(\ln y_4, \ln h)}{\operatorname{var}(\ln y_4)}}_{0.223} + \underbrace{\frac{\operatorname{var}(\ln y_5)}{\operatorname{var}(\ln y_0)}}_{0.256} \underbrace{\frac{\operatorname{cov}(\ln y_5, \ln h)}{\operatorname{var}(\ln y_5)}}_{0.574}$$

Covariance Decomposition

$$\underbrace{\frac{\operatorname{cov}(\ln y_0, \ln h)}{\operatorname{var}(\ln y_0)}}_{0.224} = \underbrace{\underbrace{\frac{\operatorname{var}(\ln y_1)}{\operatorname{var}(\ln y_0)}}_{0.102}\underbrace{\frac{\operatorname{cov}(\ln y_1, \ln h)}{\operatorname{var}(\ln y_1)}}_{0.189}}_{0.019} + \underbrace{\underbrace{\frac{\operatorname{var}(\ln y_2)}{\operatorname{var}(\ln y_0)}}_{0.932}\underbrace{\frac{\operatorname{cov}(\ln y_2, \ln h)}{\operatorname{var}(\ln y_2)}}_{0.099}}_{0.092}$$

$$+ \underbrace{\underbrace{\frac{\operatorname{var}(\ln y_3)}{\operatorname{var}(\ln y_0)}}_{0.036}\underbrace{\frac{\operatorname{cov}(\ln y_3, \ln h)}{\operatorname{var}(\ln y_3)}}_{-1.422}}_{-0.051} + \underbrace{\underbrace{\frac{\operatorname{var}(\ln y_4)}{\operatorname{var}(\ln y_0)}}_{0.069}\underbrace{\frac{\operatorname{cov}(\ln y_4, \ln h)}{\operatorname{var}(\ln y_4)}}_{0.223}}_{0.015} + \underbrace{\underbrace{\frac{\operatorname{var}(\ln y_5)}{\operatorname{var}(\ln y_0)}}_{0.256}\underbrace{\frac{\operatorname{cov}(\ln y_5, \ln h)}{\operatorname{var}(\ln y_5)}}_{0.574}}_{0.147}$$

Development Accounting Results

Productivity measures:	N	Year	Covariance measure: Total knowledge capital	Covariance measure: Test scores	Covariance measure: Years of Schooling
Sample excludes those enrolled in school					
GDP per capita (HRW 2017b)	47	2007	0.228	0.135	0.093
			(0.044)	(0.028)	(0.023)
Output per hour worked	47	2007	0.099	0.057	0.042
			(0.063)	(0.040)	(0.028)
Output per hour worked	50	2007	0.077	0.045	0.033
			(0.046)	(0.029)	(0.021)
Output per hour worked	50	2009	0.080	0.043	0.037
			(0.042)	(0.026)	(0.019)
Sample includes those enrolled in school					
Output per hour worked	50	2009	0.079	0.043	0.036
			(0.041)	(0.026)	(0.018)
Output per hour worked	50	2017	0.115	0.071	0.045
			(0.043)	(0.027)	(0.020)

Knowledge Capital and Productivity Growth (2009–2017)

$$\%\Delta y_s = \alpha + \beta_1 T_s + \beta_2 S_s + X_s \delta + \varepsilon_s$$

where

- Δy_s is the average annual growth rate in labor productivity in state *s* between 2009 and 2017
- T_s is the average test scores of the working-age population in state *s* in 2009
- S_s is the average years of schooling of the working-age population in state *s* in 2009
- X_s is a matrix of state controls including the log of initial level of output per hour in 2009, the log of capital stock per worker in 2009, percent of output in mining sector in 2009, percent of output in each NAICS supersector in 2009, the log of population density in 2010, and Census region fixed effects
- ε_s is an error term

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score					
Average years of schooling	0.796***				
	(0.290)				
Log (output per hour)	-2.082***				
	(0.486)				
Log (capital per worker)	-0.201**				
	(0.079)				
Log (population density)					
Census region fixed effects	NO				
State Industrial shares	NO				
Population weights	NO				
Constant	0.519				
	(3.778)				
R-squared	0.334				

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score					
Average years of schooling	0.796***				
	(0.290)				
Log (output per hour)	-2.082***				
	(0.486)				
Log (capital per worker)	-0.201**				
	(0.079)				
Log (population density)					
Census region fixed effects	NO				
State Industrial shares	NO				
Population weights	NO				
Constant	0.519				
	(3.778)				
R-squared	0.334				

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**			
		(0.499)			
Average years of schooling	0.796***	0.202			
	(0.290)	(0.337)			
Log (output per hour)	-2.082***	-2.103***			
	(0.486)	(0.472)			
Log (capital per worker)	-0.201**	-0.193**			
	(0.079)	(0.075)			
Log (population density)					
Census region fixed effects	NO	NO			
State Industrial shares	NO	NO			
Population weights	NO	NO			
Constant	0.519	2.887			
	(3.778)	(3.662)			
R-squared	0.334	0.400			

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**			
		(0.499)			
Average years of schooling	0.796***	0.202			
	(0.290)	(0.337)			
Log (output per hour)	-2.082***	-2.103***			
	(0.486)	(0.472)			
Log (capital per worker)	-0.201**	-0.193**			
	(0.079)	(0.075)			
Log (population density)					
Census region fixed effects	NO	NO			
State Industrial shares	NO	NO			
Population weights	NO	NO			
Constant	0.519	2.887			
	(3.778)	(3.662)			
R-squared	0.334	0.400			

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**	1.817**		
		(0.499)	(0.734)		
Average years of schooling	0.796***	0.202	0.325		
	(0.290)	(0.337)	(0.382)		
Log (output per hour)	-2.082***	-2.103***	-2.214***		
	(0.486)	(0.472)	(0.471)		
Log (capital per worker)	-0.201**	-0.193**	-0.192**		
	(0.079)	(0.075)	(0.092)		
Log (population density)					
Census region fixed effects	NO	NO	YES		
State Industrial shares	NO	NO	NO		
Population weights	NO	NO	NO		
Constant	0.519	2.887	-1.166		
	(3.778)	(3.662)	(4.847)		
R-squared	0.334	0.400	0.433		

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**	1.817**	1.902**	
		(0.499)	(0.734)	(0.782)	
Average years of schooling	0.796***	0.202	0.325	-0.323	
	(0.290)	(0.337)	(0.382)	(0.410)	
Log (output per hour)	-2.082***	-2.103***	-2.214***	-2.309**	
	(0.486)	(0.472)	(0.471)	(1.125)	
Log (capital per worker)	-0.201**	-0.193**	-0.192**	0.111	
	(0.079)	(0.075)	(0.092)	(0.126)	
Log (population density)				0.183*	
				(0.104)	
Census region fixed effects	NO	NO	YES	YES	
State Industrial shares	NO	NO	NO	YES	
Population weights	NO	NO	NO	NO	
Constant	0.519	2.887	-1.166	2.180	
	(3.778)	(3.662)	(4.847)	(5.952)	
R-squared	0.334	0.400	0.433	0.684	

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**	1.817**	1.902**	
		(0.499)	(0.734)	(0.782)	
Average years of schooling	0.796***	0.202	0.325	-0.323	
	(0.290)	(0.337)	(0.382)	(0.410)	
Log (output per hour)	-2.082***	-2.103***	-2.214***	-2.309**	
	(0.486)	(0.472)	(0.471)	(1.125)	
Log (capital per worker)	-0.201**	-0.193**	-0.192**	0.111	
	(0.079)	(0.075)	(0.092)	(0.126)	
Log (population density)				0.183*	
				(0.104)	
Census region fixed effects	NO	NO	YES	YES	
State Industrial shares	NO	NO	NO	YES	
Population weights	NO	NO	NO	NO	
Constant	0.519	2.887	-1.166	2.180	
	(3.778)	(3.662)	(4.847)	(5.952)	
R-squared	0.334	0.400	0.433	0.684	

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**	1.817**	1.902**	1.573**
		(0.499)	(0.734)	(0.782)	(0.577)
Average years of schooling	0.796***	0.202	0.325	-0.323	-0.295
	(0.290)	(0.337)	(0.382)	(0.410)	(0.543)
Log (output per hour)	-2.082***	-2.103***	-2.214***	-2.309**	-2.109
	(0.486)	(0.472)	(0.471)	(1.125)	(1.277)
Log (capital per worker)	-0.201**	-0.193**	-0.192**	0.111	-0.023
	(0.079)	(0.075)	(0.092)	(0.126)	(0.152)
Log (population density)				0.183*	0.202*
				(0.104)	(0.111)
Census region fixed effects	NO	NO	YES	YES	YES
State Industrial shares	NO	NO	NO	YES	YES
Population weights	NO	NO	NO	NO	YES
Constant	0.519	2.887	-1.166	2.180	4.811
	(3.778)	(3.662)	(4.847)	(5.952)	(6.898)
R-squared	0.334	0.400	0.433	0.684	0.676

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Labor Productivity Growth Regressions (2009–2017) (N = 50)

VARIABLES	(1)	(2)	(3)	(4)	(5)
Average test score		1.227**	1.817**	1.902**	1.573**
		(0.499)	(0.734)	(0.782)	(0.577)
Average years of schooling	0.796***	0.202	0.325	-0.323	-0.295
	(0.290)	(0.337)	(0.382)	(0.410)	(0.543)
Log (output per hour)	-2.082***	-2.103***	-2.214***	-2.309**	-2.109
	(0.486)	(0.472)	(0.471)	(1.125)	(1.277)
Log (capital per worker)	-0.201**	-0.193**	-0.192**	0.111	-0.023
	(0.079)	(0.075)	(0.092)	(0.126)	(0.152)
Log (population density)				0.183*	0.202*
				(0.104)	(0.111)
Census region fixed effects	NO	NO	YES	YES	YES
State Industrial shares	NO	NO	NO	YES	YES
Population weights	NO	NO	NO	NO	YES
Constant	0.519	2.887	-1.166	2.180	4.811
	(3.778)	(3.662)	(4.847)	(5.952)	(6.898)
R-squared	0.334	0.400	0.433	0.684	0.676

Notes: Robust standard errors are in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level; *** Significant at the 1 percent level.

Conclusion – Education Matters

- 12 percent of the variance in state-level labor productivity levels in 2017 results from differences in knowledge capital
  - 5 percent from years of schooling and 7 percent from test scores
- Increasing test scores by one standard deviation is associated with a 1.6-percentage-point-faster average annual productivity growth rate (2009-2017)

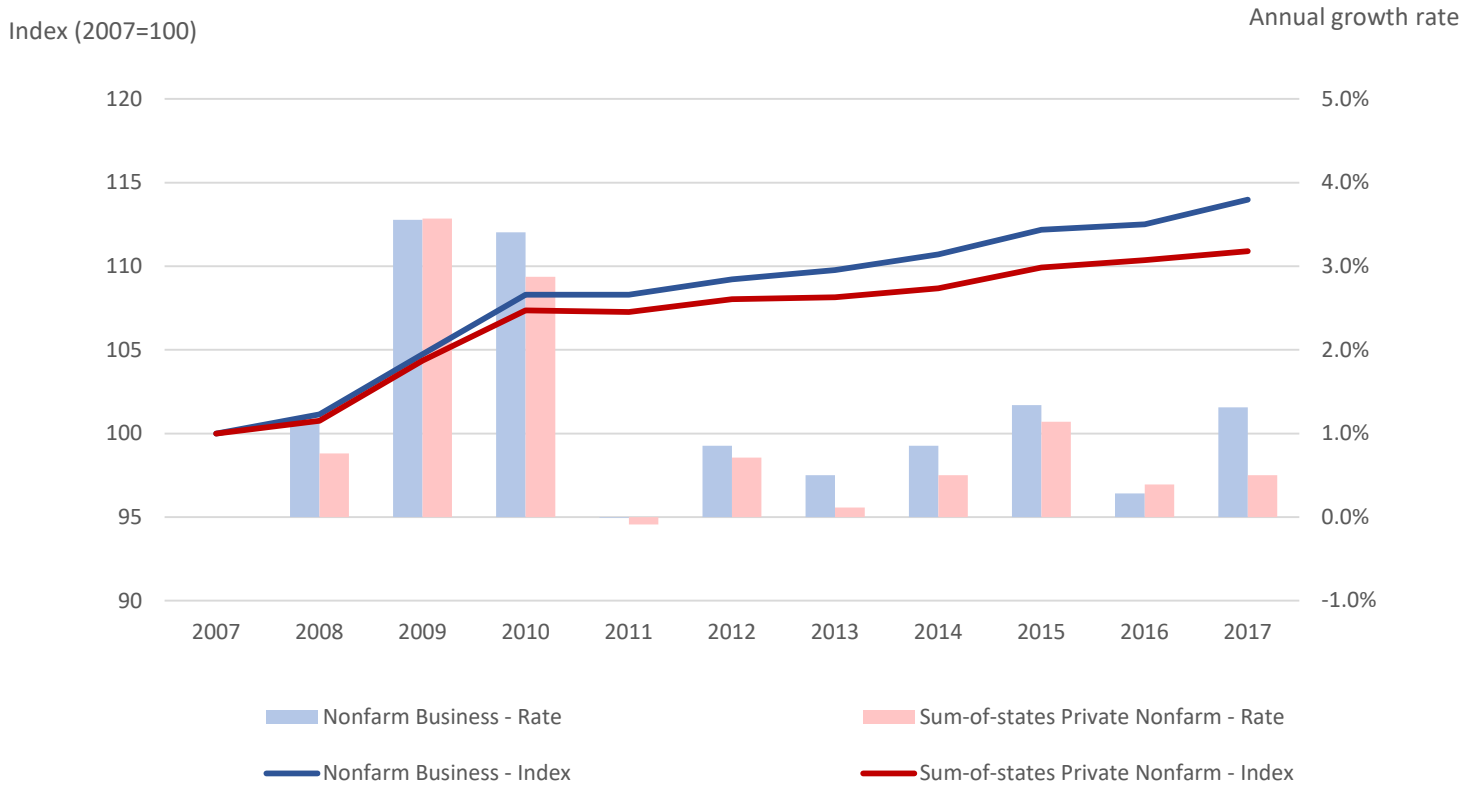
Contact Information

Sabrina Wulff Pabilonia
U.S. Bureau of Labor Statistics
Pabilonia.Sabrina@bls.gov

www.bls.gov/lpc/state-productivity.htm

EXTRA SLIDES

Trends in Labor Productivity: Sum-of-the-states Private Nonfarm versus PFEI Nonfarm Business



Source: U.S. Bureau of Labor Statistics (2019)

Varying Returns to Non-tertiary and Tertiary Years of Schooling

			Covariance measure		
Productivity measures:	N	Year	Total knowledge capital	Test scores	Years of Schooling
Sample excludes those enrolled in school					
GDP per capita (HRW 2017b)	47	2007	0.315	0.135	0.180
			(0.052)	(0.028)	(0.032)
Output per hour worked	47	2007	0.158	0.057	0.100
			(0.078)	(0.040)	(0.042)

w = 0.17 per standard deviation in test scores
r = 0.057 per year of non-tertiary schooling
r = 0.157 per year of tertiary schooling