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Thor Berger & Carl Benedikt Frey

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Industrial Renewal in the 21st Century: Evidence from US Cities

THOR BERGER†* and CARL BENEDIKT FREY‡
†*Department of Economic History, School of Economics and Management, Lund University, Lund, Sweden. Email:* thor.berger@ekh.lu.se
‡*Oxford Martin School, University of Oxford, Oxford, UK. Email:* carl.frey@oxfordmartin.ox.ac.uk

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BERGER T. and FREY C. B. Industrial renewal in the 21st century: evidence from US cities, *Regional Studies*. Where and why do new industries emerge? Using revisions of official industrial classifications, this paper documents the appearance of new industries in the US economy between 2000 and 2010 stemming directly from technological advances. Examining differences in new industry creation across cities, this paper shows that new industries mainly emerge in human capital abundant places and cities that specialize in industries that demand similar skills. Instrumental variables estimates that exploit the location of 19th-century land-grant colleges as an instrument for contemporary differences in human capital assigns a causal interpretation to these results.

Cities New industries Human capital Technological change

BERGER T. and FREY C. B. 二十一世纪的工业復兴：来自美国城市的证据，*区域研究*。新兴产业在何处、以及为何兴起？本文运用修订后的官方产业分类，纪录从 2000 年到 2010 年之间，美国经济中直接源自于技术革新的新兴产业。本文检视各城市创造新兴产业的差异，显示新兴产业主要是从专司需要类似技能的产业、且人力资本充沛的地方及城市中兴起。将十九世纪赠地大学区位视为促成当代人力资源差异的工具变量评估，对此般结果提出了因果性的诠释。

城市 新兴产业 人力资本 技术转变

BERGER T. et FREY C. B. Le renouveau industriel au cours du 21e siècle: des résultats provenant des grandes villes situées aux É-U, *Regional Studies*. D'où et pourquoi les nouvelles industries est-ce qu'elles apparaissent? À partir des modifications des nomenclatures industrielles officielles, cet article documente la naissance des nouvelles industries dans l'économie aux É-U entre l'an 2000 et 2010 qui est directement le résultat des avances technologiques. En examinant à travers les grandes villes les différences de la création de nouvelles industries, cet article montre que les nouvelles industries apparaissent principalement dans des lieux et des grandes villes abondants en capital humain et qui se spécialisent dans les industries qui exigent des compétences similaires. Des estimations des variables instrumentales, qui exploitent l'emplacement des land-grant colleges du 19e siècle (universités aux É-U construites à partir d'une concession foncière faite par le gouvernement fédéral) comme outil des différences contemporaines du capital humain, attribuent une interprétation causale à ces résultats.

Grandes villes Nouvelles industries Capital humain Mutation technologique

BERGER T. und FREY C. B. Die Entstehung neuer Branchen im 21. Jahrhundert: Belege aus Städten der USA, *Regional Studies*. Wo und warum entstehen neue Branchen? Anhand einer Überprüfung der offiziellen Branchenklassifikationen wird in diesem Beitrag das Entstehen von neuen Branchen in der Wirtschaft der USA als unmittelbares Resultat technischer Neuerungen im Zeitraum von 2000 bis 2010 untersucht. Durch eine Untersuchung der Unterschiede bei der Entstehung neuer Branchen in verschiedenen Städten zeigen wir, dass neue Branchen vor allem in Orten mit reichlich Humankapital sowie in Städten entstehen, die auf Branchen spezialisiert sind, für die ähnliche Qualifikationen erforderlich sind. Zur kausalen Interpretation dieser Ergebnisse nutzen wir Instrumentalvariablenschätzungen, in denen der Standort von Land-Grant-Colleges des 19. Jahrhunderts als Instrument für aktuelle Unterschiede beim Humankapital genutzt wird.

Städte Neue Branchen Humankapital Technischer Wandel

BERGER T. y FREY C. B. Renovación industrial en el siglo XXI: ejemplo de ciudades estadounidenses, *Regional Studies*. ¿Dónde y por qué surgen nuevas industrias? A partir de un examen de las clasificaciones industriales oficiales, en este artículo documentamos la aparición de nuevas industrias en la economía estadounidense entre 2000 y 2010 que proceden directamente de los progresos

*Corresponding author.

tecnológicos. Examinando las diferencias entre la creación de nuevas industrias en varias ciudades, mostramos que las nuevas industrias surgen principalmente en lugares con abundante capital humano y en ciudades especializadas en industrias que exigen calificaciones similares. Para hacer una interpretación causal de estos resultados, calculamos las variables instrumentales utilizando la ubicación de universidades del siglo XIX por cesión de terreno como un instrumento para las diferencias contemporáneas en el capital humano.

Ciudades Industrias nuevas Capital humano Cambio tecnológico

JEL classifications: J24, O31, O33, R11

INTRODUCTION

Over recent decades, the US economy has witnessed a decline in indicators of technological dynamism, contributing to a growing concern about its capacity to create new work as old industries mature and decline (Decker *et al.*, 2014; Haltiwanger *et al.*, 2014). In particular, the falling pace of job reallocation and new firm formation has induced a debate about whether the age of Schumpeterian growth is over (Gordon, 2012). Yet, while such indicators are informative, they tend to obscure the extent to which new jobs and companies are created as a result of technological innovation.

This paper develops a novel approach to identify the creation of *new* industries associated with technological change that captures the 'creative destruction' Joseph Schumpeter (Schumpeter, 1939) famously labelled an essential fact about economic growth.[1] Using revisions of the US Census Bureau's *Alphabetical Index of Industries*, including some 22 000 industry titles used to classify respondents' industry, this paper systematically identifies industries that appeared for the first time between the year 2000 and 2010. Doing so, it advances the literature on industrial branching in cities and regions, often defining 'new' industries as the entry of industries that did not previously exist in a location (Frenken and Boschma, 2007; Neffke *et al.*, 2011a; Boschma *et al.*, 2012, 2013; Essletzbichler, 2013; Muneepeerakul *et al.*, 2013), which may simply reflect life-cycle patterns of industry diffusion (Duranton and Puga, 2001; Duranton, 2007; Neffke *et al.*, 2011b), or long-run trends in the concentration of industrial activity (Kim, 1995). This approach is employed to examine why some cities have managed to reinvent themselves to take advantage of the digital revolution of the 2000s, while others have failed to create new industries. Building on the idea that new production methods and organizational changes increasingly favour skilled workers and that new industries cluster to benefit from knowledge spillovers (Jacobs, 1969; Duranton and Puga, 2001; Desmet and Rossi-Hansberg, 2009), this paper tests the hypothesis that new industries are more likely to emerge in skilled cities.

Using data on 1.2 million workers from the 2010 American Community Survey (ACS), it is shown that new industries tend to employ more skilled workers than existing ones and primarily locate in cities with an above-average supply of college-educated workers. Overall, the magnitude of job creation in new industries is however strikingly small: in 2010, about 0.5% of the US workforce was employed in industries that did not exist a decade earlier, although there is substantial variation across locations. In skilled cities like San Jose, incorporating Silicon Valley, about 1.8% of workers are employed in new industries, compared with 0.2% in Grand Rapids. The importance of skill abundance to industrial renewal is further documented in Fig. 1, showing a strong positive link between the percentage of college-educated workers in the year 2000 and the share of workers in industries that were created between 2000 and 2010, across US cities.

Regression evidence shows that this relationship persists when controlling for a range of city characteristics, using within-state variation in skills and new industry creation, and in alternative samples. Furthermore, placebo estimates that examine the relationship between skills and the emergence of *non*-technology industries are close to zero and not statistically significant, suggesting that the estimates capture the relationship between skills and the creation of new technology-related industries.

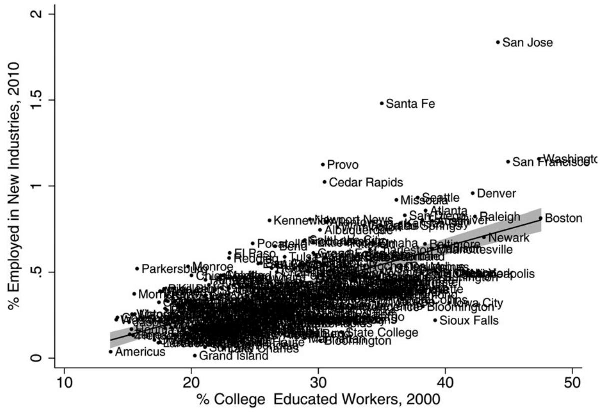

Fig. 1. *New industry creation and human capital in US cities*
Note: The percentage of workers employed in industries that were created between 2000 and 2010 and the percentage of each city's workers with a bachelor's degree or higher in 2000 across 321 US cities are shown. See the main text for a discussion of the underlying data

While the mechanism underlying the link between human capital and new industry creation may reflect that skilled cities are better able to adapt to new technologies to reinvent themselves (GLAESER and SAIZ, 2004), it could also stem from skilled cities being more innovative. To shed some light on the relative importance of the 'reinvention' and 'innovation' hypothesis, this paper also examines the extent to which new industries emerge as the result of local innovation rather than the implementation of new technologies invented elsewhere. Crucially, controlling for local levels of innovation, measured by patenting rates, leaves the link between human capital and new industry creation intact. Thus, while there is a positive link between local innovation and industrial renewal, a continued robust relationship between skills and the creation of new industries suggests that industrial renewal mainly stems from skilled workers being better able to adapt to technological change.

To examine further the causal relationship between human capital abundance and industrial renewal, alternative identification strategies are used. It is shown that net of individual observable characteristics workers are more likely to be observed in a new industry in cities endowed with skilled workers. While this rules out that the link merely reflects observable differences between workers in skilled cities and other locations, it does, however, not rule out the possibility that omitted city characteristics drive the relationship between skill endowments and industrial renewal. To address this concern, this paper employs an instrumental variables (IV) strategy that exploits the location of land-grant colleges, established by the federal Morrill Act of 1862, as an instrument for contemporary differences in human capital (MORETTI, 2004). Because these institutions were established some 150 years ago and supported by federal grants that were not allocated primarily on the basis of economic considerations, the presence of a land-grant college is unlikely to affect the creation of new industries in the 2000s, other than by raising local human capital levels. Although IV estimates are smaller than the ordinary least squares (OLS) estimates, suggesting an upward bias in the correlation shown in Fig. 1, the findings suggest that this nonetheless reflects a causal relationship between local skill endowments and spatial differences in industrial renewal.

This paper is related to several literatures. First, it adds to a series of papers showing that education is a key predictor of city growth (RAUCH, 1993; GLAESER *et al.*, 1995; SIMON and NARDINELLI, 2002; GLAESER and SAIZ, 2004; SHAPIRO, 2006), and a subset of this literature documenting a divergence in human capital levels across US cities over the post-war period. In the model of BERRY and GLAESER (2005), for example, this divergence stems from the tendency of skilled entrepreneurs to innovate in ways that create employment opportunities for more skilled workers. The findings in this paper provide an empirical counterpart to this prediction, showing that new industries mainly emerge in skilled cities, and that skilled workers are more likely to be observed in new work.

Second, the results are related to a vast literature on skill-biased technological change, showing that almost all industries began employing more educated workers during the 1970s and 1980s (BERMAN *et al.*, 1994; AUTOR *et al.*, 1998; MACHIN and VAN REENEN, 1998). Nevertheless, BEAUDRY *et al.* (2013) document a decline in the demand for skill within existing occupations and industries over the past decade, implying a reversal in the direction of technological change. By contrast, when examining workers in new industries, stemming directly from the arrival of new technologies, this paper finds evidence of skill-biased technological change throughout the 2000s: workers in new industries are substantially better educated and earn more than twice the US median wage. However, because only a fraction of workers are employed in new industries, the impact of new work on the aggregate demand for skills is likely to be negligible.

NEW INDUSTRIES IN THE 21ST CENTURY

Data sources and measurement

Data: alphabetic index of industries. To capture systematically the appearance of new industries, this paper uses the 2000 and 2010 editions of the *Alphabetic Index of Industries*, constructed and used by the US Census Bureau to classify census respondents' industry as reported in demographic surveys. Crucially, each *Index* reports more than 21 000 finely grained industry titles, in many instances directly corresponding to a product or service. Through reviews of census survey responses, the *Index* is continuously updated over time, which makes it suitable to track how new technologies lead to the emergence of new industries. According to the US Census Bureau (see http://www.census.gov/people/io/about/industry.html), these

> changes are needed to recognize the 'birth' of new occupations and industries, the 'death' of others, the growth and decline in existing categories, and the desire of analysts and other users for more detail in the presentation of the data.

First, a string match is performed between each individual title in the 2010 *Index* against titles in the 2000 edition, yielding 283 unique industry titles that appeared for the first time during the 2000s. Some new titles are, however, simply the result of reclassifications or the division of existing industries. To isolate industries emerging as a result of new technologies becoming available, a manual review of the 283 titles was performed, categorizing them according to the underlying reason for their emergence. By manually screening each new title, comparing them with all titles in the corresponding detailed industry, titles that constitute reclassifications or old titles being split into more detailed titles are identified and excluded. Similarly, new titles that stem from import substitution or changing consumer preferences are eliminated. For example, while yam production has been a core industry in Nigeria for decades, it only emerged as a sufficiently significant industry in the United States to constitute a title in 2010.[2] Finally, public industries (e.g., Department of Homeland Security), all residual titles (e.g., automotive any other) and individual companies that have a unique title (e.g., eBay) are excluded from the sample.

Doing so, 212 new industry titles are eliminated, leaving 71 titles that are directly related to technological advances. For example, the emergence of the video and audio streaming industry would not have been possible without the simultaneous development of several technologies. By the early 2000s, increased bandwidth for consumers, more powerful computers and the diffusion of the internet solved the primary technical issues related to online streaming. In 1999, Apple introduced media streaming in QuickTime; and in 2002, Adobe developed Flash, the streaming format that still constitutes the backbone of YouTube. In a similar fashion, internet news publishers, social networking services and internet video broadcast sites correspond to new industries arising from the advent of the World Wide Web in the 1990s: more than 70% of the new titles observed are related to digital technologies. Other new titles, such as wind farms and biotechnology food research, similarly reflect technological progress. Additional examples of new industries and descriptive statistics are provided in Appendix A in the supplemental data online.

Micro-level data. To analyze the characteristics of workers in new industries, industry titles from the 2010 *Index* are matched to the detailed industries reported in the 2010 ACS microdata samples (Ruggles *et al.*, 2010). For each industry title, the 2010 *Index* also report 2010 Census industry codes, which makes it straightforward to match industry titles to their corresponding detailed industries. The sample is restricted to individuals aged 18–65 years, outside Alaska and Hawaii, who do not live in group quarters and with industry responses that can be matched with data from the *Index*.

However, since the microdata samples only report detailed industry codes (e.g., industry 5591, Electronic Auctions), actual employment in new industry titles are not observed (e.g., in the corresponding title internet auction sites). Instead, following Lin (2011), this paper estimates the probability n_m that a worker is employed in a new industry, where

$$n_m = v_m / t_m$$

corresponds to the number of new titles (v) divided by the total number of titles (t) in each detailed industry m respectively. Although this approach relies on the assumption that workers are evenly distributed across titles within detailed industries, violations of this assumption would introduce little bias in cross-city comparison of new industry creation.

To examine the spatial variation in new industry employment, workers are assigned to commuting zones (CZs), using crosswalks from Autor and Dorn (2013). CZ boundaries reflect local labour markets, identified based on county-level commuting patterns (Tolbert and Sizer, 1996). The empirical analysis focuses on the 321 urban CZs, which interchangeably are referred to as 'cities' throughout the paper.[3]

THE DETERMINANTS OF NEW INDUSTRY CREATION

Empirical implementation

To examine the link between new industry creation and skills across US cities, OLS regressions of the following form are estimated:

$$n_{cs} = \alpha + \zeta_s + \delta C_{cs} + Z_{cs}\theta + \varepsilon_{cs} \quad (1)$$

where n denotes the percentage of workers in city c, in state s, who are employed in industries that appeared for the first time between 2000 and 2010; α is a constant; ζ is a set of state fixed effects; C is the percentage of the workforce with at least a bachelor's degree in 2000; $\mathbf{Z}$ is a vector of control variables; and $\boldsymbol{\varepsilon}$ is an error term.

One concern is that the concentration of skills reflect some other underlying factor, leading to omitted variable bias in the regressions, in which case the correlation between local skills and the creation of new industries may be spurious. Such concerns are addressed in three ways. First, a number of city characteristics are included in $\mathbf{Z}$ to control for potentially omitted variables: the log size of each city's population in 2000, average household income in 2000, income growth between 2000 and 2010, and the fraction of the population that is black and foreign born respectively.[4] In addition, to address concerns that a historical dependence on manufacturing may have caused some cities to lose their ability to reinvent themselves (Glaeser and Saiz, 2004), controls for the share of employed workers, 16 years and older, working in manufacturing in 2000 and exposure to Chinese imports during the 1990s from Autor *et al.* (2013) are included. Additional specifications, discussed in more detail below, explore the role of local innovation, concentrations of related industries and the presence of universities.

Following Lin (2011), the second approach consists of replacing the outcome variable with residuals from individual-level regressions of the probability of being employed in a new industry to adjust for compositional differences between cities. In practice, this entails estimating:

$$n_{ics} = \alpha + \mathbf{X}'_{ics}\boldsymbol{\theta} + \nu_{ics} \qquad (2)$$

where n_{ics} corresponds to the probability that a worker i, in city c, is observed in employment in a new industry; and $\mathbf{X}'_{ics}$ includes age and its square, as well as dummies for race, sex, marital status, a full set of major industry and state fixed effects, and educational attainment.[5] In a second step, the vector of estimates $\boldsymbol{\theta}$ is used to predict the residual probability of a worker being employed in a new industry, which corresponds to the likelihood of being observed in a new industry, net of observable individual characteristics. These residuals are then averaged for each city, using workers' census weights. For each city, this allows an examination of additions of new industries, net of variation that arises from compositional differences due to demographics, industrial specialization or the spatial sorting of workers across cities.[6]

OLS estimates may still be biased if some omitted factor that drives the locational choices of skilled workers also is correlated with the creation of new industries. In particular, if skilled workers are attracted to cities with, for example, a more favourable local business climate, which also may positively contribute to the creation of new industries, OLS estimates of δ may be upward biased. A third approach therefore exploits a historical source of variation in human capital across US cities that predates the digital revolution by some 150 years.

IV strategy: 1862 land-grant colleges. A key predictor of differences in education between cities is the presence of universities. However, as emphasized by Moretti (2004), the location of universities is non-random, making them unsuitable as an instrument for differences in human capital. The IV strategy therefore exploits the location of land-grant colleges, established in the 19th century, as an exogenous source of variation in human capital levels across US cities.[7] These colleges were established following the federal Morrill Act of 1862 – the first major US federal programme to support higher education – which donated public land to states, intended to raise endowments for the establishment of college institutions.

Although a complex set of factors determined the location of each individual land-grant institution, there is little evidence to suggest that their location was determined by economic considerations, with many colleges established in rural areas (Nevins, 1962; Edmond, 1978; Williams, 2010). Moreover, because the land-grant programme was federal, introduced more than a century ago, and largely focused on the agricultural and mechanical arts, it is unlikely that their location affects the creation of new industries today other than through higher contemporary levels of human capital.[8] However, the exclusion restriction may be violated if the presence of a land-grant college affects the creation of new industries through channels other than education, such as interactions between local firms and university staff, or research spillovers. To mitigate this concern, the specifications control for modern measures of university presence, so that for the exclusion restriction to hold it only requires that the location of land-grant institutions is uncorrelated with any omitted variable conditional on these controls.[9]

Main results

Table 1 presents the main results, from estimating equation (1), showing that between 2000 and 2010 employment in new industries expanded more in cities with an abundance of college-educated workers. Column (1) shows the bivariate correlation between the share of the workforce with at least a bachelor's degree in 2000, and the fraction of workers employed in new industries by 2010 in each city (also shown in Fig. 1), which implies that a 1 SD (standard deviation) increase in a city's share of workers with a college degree is associated with a 0.67 SD increase in the share of workers employed in new industries. Adding city controls and a full set of state fixed effects reduces magnitudes somewhat (columns 2 and 3), but leaves a sizable effect of local skills on industrial renewal.

Following an emerging literature suggesting that the presence of related skills is crucial to industrial branching (Klepper, 2002; Neffke and Henning, 2013; Boschma *et al.*, 2012), the impact of related industries is further examined. Because most new titles are related to digital technologies, the focus is on the presence of skills associated with information technology (IT) industries. When controlling for the share of the workforce in IT industries in 2000 (column 4), the coefficient on human capital decreases slightly, suggesting that the general human capital effect partly reflects the abundance of related skills. The abundance of IT industry-related skills in 2000 is also a statistically significant predictor of new industry creation, implying that such skills are important to a city's capacity to create new industries. However, even when controlling for IT specialization, there is a large and statistically significant effect of the share of college-educated workers on industrial renewal.[10]

In principle, there are two possible mechanisms underlying the link between human capital abundance and the creation of new industries. As suggested by Duranton (2007), industries may churn in response to new breakthrough innovations, leading them to move where innovations emerge. The 'innovation hypothesis' in other words implies that the emergence of new industries reflects that skilled cities exhibit higher rates of local innovation (Carlino *et al.*, 2005; Doms *et al.*, 2010). A second mechanism resonates with the 'reinvention hypothesis' of Glaeser and Saiz (2004), suggesting that skilled cities are more prone to adapt to technological advances and reinvent themselves, without necessarily

Table 1. New industry creation and human capital in US cities, 2000–10

	Outcome: percentage of city employment in new industries, 2010					
	(1)	(2)	(3)	(4)	(5)	(6)
Percentage with a college degree, 2000	0.023*** (0.002)	0.017*** (0.003)	0.019*** (0.004)	0.012*** (0.003)	0.014*** (0.004)	0.018*** (0.003)
Percentage in computer industries, 2000				0.064*** (0.018)		
ln Patents (%), 2000–10					0.044** (0.017)	
Number of colleges (%), 2000						2.010*** (0.521)
City characteristics?	No	Yes	Yes	Yes	Yes	Yes
State FE?	No	No	Yes	Yes	Yes	Yes
Observations	321	321	321	321	320	317
R^2	0.41	0.48	0.61	0.67	0.63	0.63

Notes: Ordinary least squares (OLS) estimates of equation (1) are presented, where the outcome is the percentage of each city's workers who are employed in industries that appeared for the first time between 2000 and 2010.

Statistical significance based on robust standard errors clustered at the state level is denoted by $***p < 0.01$, $**p < 0.05$ and $*p < 0.10$.

experiencing higher rates of local innovation. Over the last century, cities with more human capital have indeed grown faster relative to less skilled cities, lending support to the idea that an abundance of skills help cities reinvent themselves through adaptation to new technologies (e.g., GLAESER *et al.*, 1995; SIMON and NARDINELLI, 1996, 2002; HENDERSON and BLACK, 1999; BEAUDRY *et al.*, 2010; GLAESER *et al.*, 2012).

To shed some light on the relative importance of the 'innovation' and 'reinvention' hypothesis, column (5) controls for the count of utility patents per capita in each city, granted by the US Patent and Trademark Office (USPTO) between 2000 and 2010.[11] While patents may provide a noisy indicator for innovation, as some innovations are not patented and patents are sometimes used for strategic reasons, LIN (2011) finds a positive relationship between patents and the emergence of new occupations across cities. If the relationship between cities' human capital and new industry creation exclusively reflects higher levels of local innovation, controlling for innovation rates would project the entire effect onto the innovation indicator, leaving the human capital effect close to zero. However, while more innovative cities, as captured by higher rates of patenting, are better at creating employment in new industries, the link between human capital and new industry creation remains, even though the magnitude is slightly reduced. Although this is not to be viewed as conclusive evidence, these results support an interpretation of new industry creation being primarily driven by skilled workers implementing new technologies rather than necessarily inventing them, though the fact that there exists a positive correlation between local rates of patenting and new industry creation lends some empirical support to the 'innovation' hypothesis.

Nevertheless, variation in human capital levels between cities may partly reflect the presence of universities (WINTERS 2011), which in itself may affect differences in the creation of new industries through, for example, research spillovers (ANDERSSON *et al.*, 2004, 2009). To address this concern, column (6) adds control for the number of colleges per capita.[12] Although the presence of universities is positively related to the appearance of new industries, it leaves the link between local human capital and new industry creation largely unaffected. These results contrast the findings of FALLAH *et al.* (2014): examining the differences in high-tech employment growth across US counties, they found no evidence for the proximity to universities, including the land-grant institutions, boosting growth. Thus, these findings suggest that the factors determining the growth of employment in existing high-tech jobs are not necessarily the same that determine where new types of jobs emerge.

The analysis next proceeds to examine whether the probability that a worker living in a skilled city will transition into a new industry is higher, relative to an observationally similar worker living in a less skilled city. Table 2 shows results from estimating equation (2), where the left-hand-side variable is replaced with city averages of residuals from individual-level regressions, capturing the probability of being observed in a new industry net of worker characteristics and a set of industry and state dummies. Even when controlling for a range of observable worker characteristics in the first stage, a positive and statistically relationship persists between city-level skills and the creation of new industries. Thus, the main results do not simply reflect that workers in skilled cities differ in observable ways from those in less skilled cities.

Further robustness checks are provided in Appendix A in the supplemental data online, which shows that results are robust to including rural CZs, excluding outliers, controlling for a historical reliance on manufacturing, as well

Table 2. Addressing worker selection

	Outcome: residual employment in new industries, 2010	
	(1)	(2)
Percentage with a college degree, 2000	0.008***	0.010***
	(0.002)	(0.003)
City characteristics?	No	Yes
State FE?	Yes	Yes
Observations	321	321
R^2	0.36	0.42

Note: Ordinary least squares (OLS) estimates of equation (3↑) are presented, where the outcome corresponds to the averaged residuals from individual-level regressions of the probability of employment in a new industry on demographic, educational and industry controls. Statistical significance based on robust standard errors clustered at the state level is denoted by $***p < 0.01$, $**p < 0.05$ and $*p < 0.10$.

Table 3. Instrumental variables (IV) estimates (two-stage least squares (2SLS))

	(1)	(2)	(3)
(A) *First stage (outcome: percentage with a college degree, 2000)*			
Distance to 1862 land-grant college (ln)	−2.936***	−2.556***	−2.560***
	(0.628)	(0.445)	(0.445)
(B) *Second stage (outcome: percentage of city employment in new industries, 2010*			
Percentage with a college degree, 2000	0.014***	0.013**	0.018*
	(0.005)	(0.006)	(0.01)
City characteristics?	No	Yes	Yes
State FE?	Yes	Yes	Yes
University controls?	No	No	Yes
Observations	321	321	317
Kleibergen–Paap *F*-statistic	21.9	32.9	16.6

Note: The first stage documents the negative relationship between each city's (ln) distance to the nearest 1862 land-grant institution and the percentage of the labour force with a college degree in 2000. The second stage uses this source of variation in the skill mix of cities today to predict the creation of new industries between 2000 and 2010. Statistical significance based on robust standard errors clustered at the state level is denoted by $***p < 0.01$, $**p < 0.05$ and $*p < 0.10$.

as alternative definitions of new industry titles. Importantly, a placebo test that examines the link between skills and new *non*-technology related new industries yields an estimate that is close to zero and not statistically significant, which reduces concerns that the results reflect a mechanical correlation between human capital and new industry classifications.

IV results. OLS estimates presented in the previous section may be upward biased, to the extent that omitted factors that drive new industry creation are also correlated with the skill level of cities. To that end, Table 3 reports two-stage least squares (2SLS) estimates from using each city's distance to the nearest 1862 land-grant college to predict differences in city-level education in the first stage. Panel A documents the first-stage relationship, showing that a larger share of the workforce in cities closer to a historical land-grant college had a college degree in 2000. As emphasized by a large literature, weak instruments may lead to biased estimates (Bound *et al.*, 1995; Staiger and Stock, 1997; Stock *et al.*, 2002), though large *F*-statistics in the first stage largely reduce such concerns.[13]

Panel B reports the second-stage results, where the variation in human capital due to the location of the land-grant institutions is used to examine the impact of skills on new industry creation. From comparing the IV estimate reported in Table 3 (column 2) with the corresponding OLS estimate (reported in Table 1, column 3), it is clear that the IV estimate is smaller in magnitude. One explanation for this difference is that there are omitted factors that have affected both the locational choices of skilled workers and the recent creation of new industries, which leads to an upward bias of the OLS estimates. Using the variation in human capital that is driven by the location of the historical land-grant institutions likely corrects for such factors that have changed over recent decades. Column (3) directly controls for the fact that cities located close to historical land-grant colleges also are more likely to be closer to a university today by including a control for the number of colleges per capita which slightly increases, rather than reduces, the second stage estimate.

In sum, this analysis suggests a causal effect of skill abundance on new industry creation, although it also shows that the simple correlation between skills and new industry creation is likely to overstate the strength of this relationship. A remaining empirical concern is that the land-grant institutions may differ from other universities today in ways that positively contribute to new industry creation. However, in a regression of new industry creation on the distance to the nearest land-grant institution, this variable is close to zero and not statistically significant when the share of a city's workforce with a college degree is also included.[14] Although one cannot definitely rule out that there is some unobserved factor that is correlated with the location of the land-grant institutions also affecting new industry creation, the IV estimates suggest that cities in the United States where skilled workers historically have located are also places that have experienced substantially more rapid industrial renewal in the 21st century.

CONCLUSIONS: CITIES AND THE CREATION OF NEW INDUSTRIES

A central contribution of this paper is to document employment opportunities created in entirely new industries – that appeared for the first time between 2000 and 2010 – associated with the arrival of new technologies. These data are used to examine the determinants of new industry creation, showing that new industries are more likely to emerge in human capital abundant places and cities that specialize in industries that demand similar skills.

Yet, the magnitude of workers shifting into new industries is strikingly small: in 2010, only 0.5% of the US labour force is employed in industries that did not exist in 2000. Crucially, it is found that many new industries of the 2000s stem from the digital revolution, including online auctions, internet news publishers, social networking services and the video and audio streaming industry. Relative to major corporations of the early computer revolution, the companies leading the digital revolution have created few employment opportunities: while IBM and Dell still employed 431 212 and 108 800 workers respectively, Facebook's headcount reached only 7185 in 2013. Because digital businesses require only limited capital investment, employment opportunities created by technological change may continue to stagnate as the US economy is becoming increasingly digitized. How firms and individuals are responding to digital technologies becoming available is a line of enquiry that deserves further attention.

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NOTES

1. For brevity, this paper interchangeably refers to new 'technology-related' industries simply as 'new industries' throughout.
2. Similarly, while flea markets are now for the first time sufficiently popular to constitute an industry, the first flea markets in the United States date back to the Canton Monday Trade Days beginning in 1873.
3. Urban status is defined based on whether a CZ intersects a metropolitan statistical area. The robustness checks reported in Appendix A in the supplemental data online shows that the main results are similar, though smaller in magnitude, in a sample that also includes the rural CZs.
4. Controls are based on the 2000 Census. While income growth between 2000 and 2010 may be endogenous to new industry creation, this control variable is thought of as capturing a wide range of productivity shocks that may be correlated with the creation of new industries.
5. Educational attainment is captured by a dummy for a bachelor's degree, a master's degree, a professional degree, a PhD and whether the degree is in a science, technology, engineering and mathematics (STEM) field respectively.
6. While this approach addresses spatial sorting based on observable characteristics, sorting on unobservable ability may still bias the estimates upwards if more able workers select cities with a larger fraction of skilled workers.
7. Moretti (2004) uses the location of the land-grant institutions to study the extent of human capital spillovers.
8. Kantor and Whalley (2014) examine the long-run impact of US agricultural experiment stations, established following the Hatch Act of 1887 that provided federal funding to establish experiment stations at the land-grant colleges. However, they show that the productivity effects of these stations in most instances had faded already by the 1920s, with little impact on productivity differences today.
9. More precisely, it requires that the land-grant institutions do not differ in important dimensions from other universities. In support of this assumption, Moretti (2004) shows that workers in cities with a land-grant college differ little from workers in cities without a land-grant institution in terms of demographic and racial characteristics as well as Armed Forces Qualification Test (AFQT) scores.
10. The share of workers with a college education remains a statistically significant predictor of new industry creation also when focusing only on the 51 new industries that are associated with digital technology, holding each city's share of workers employed in IT industries constant. A 1 SD (standard deviation) increase in the share of college-educated workers is associated with roughly 0.67 SD increase in new digital industry employment, suggesting that general human capital is important over and above related skills.
11. Patents are assigned to counties based on the location of residence of the first-named inventor, which may differ from the location of work, although this should induce negligible bias in the estimations. Publicly available county-level patent counts from the USPTO are matched with CZs, using crosswalks available from the US Department of Agriculture (USDA).
12. More precisely, it includes controls for the number of title IV degree-offering institutions per capita and the income-adjusted college graduation rate based on Chetty *et al.* (2014).
13. The corresponding Stock and Yogo (2005) critical value for a maximum 10% IV bias is 16.38 for one endogenous regressor and one instrument, meaning that one can clearly reject the null of weak instruments.

14. An additional threat to the validity of these estimates is that employment in IT clusters or patenting activity may be higher in cities in proximity to the land-grant institutions. However, controlling for the share of workers employed in the IT industry and the average number of patents per university only slightly reduces the coefficient on the share of college-educated workers respectively to 0.013 ($p = 0.019$) and 0.011 ($p = 0.046$) in the second stage.

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