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An Occupational Approach to Analyzing Regional Invention

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Abstract

The purpose of this working paper is to refine and evaluate the occupation-driven approach for analyzing regional invention suggested by Wojan, Dotzel, and Low (2015), who argue that patenting rates should be computed on the subset of workers that might plausibly contribute to patenting. We introduce several modifications to their original analysis, including use of a special tabulation of more detailed occupation data and added controls for regional characteristics that could confound identification of the inventive class—the group of occupations most associated with patent production. We then critically evaluate the findings by implementing a simultaneous equations model of the interrelationship between the composition and productivity of the inventive class. Substitutions of alternative subpopulations of knowledge workers such as the college-educated population for the inventive class allow us to assess the value added of the updated inventive class construct. Simultaneous equations results confirm the existence of an interrelationship between patent production and membership in the inventive class in rural regions and highlight an apparent disarticulation of inventive employment and patent-intensive manufacturing employment in urban areas.

Introduction

Though not escaping criticism, patents per capita has endured as the default metric for regional inventive capacity for the past 30 years, a dependence that can largely be credited to the absence of a compelling alternative (Galindo-Rueda 2013; Usai 2011; Krammer 2009; Organisation for Economic Co-operation and Development [OECD] 2009, 2010; Carlino, Chatterjee, and Hunt 2007; Griliches 1990). As the inventive capacity of regions becomes more central to understanding the innovation economy, a metric of convenience may impose significant costs. In the past decade, patenting productivity in the United States, measured as number of patents granted to American inventors per capita, has reached levels rivaling those seen during the Industrial Revolution and post-Civil War era (Rothwell et al. 2013). Continued reliance on patents per capita will erroneously discount the patenting productivity of regions highly amenable to less-patentable ventures, such as tourism and the arts, while unquestionably exalting the patenting prowess of high-technology clusters with workforces dominated by inventive workers.

If patenting is largely reliant on occupation-specific human capital, then a valid analysis of the phenomenon should incorporate this fundamental input. In a 2015 publication, Wojan, Dotzel, and Low draw a parallel between demography and the economics of invention to illuminate this argument. Just as a fertility rate is calculated on a denominator of women of child-bearing age, a regional patenting rate should be computed on the subset of the population that might plausibly contribute to patenting. Identifying that subset—an inventive class—is done empirically using an iterative regression technique to uncover the occupations strongly associated with patent production. This parallel to demography extends to traditional standardization and decomposition techniques that distinguish between scale- and productivity-based differences in patent production across regions.

In this study, we introduce several modifications to Wojan, Dotzel, and Low's (2015) original analysis, including use of a special tabulation of more detailed occupation data from the Census Bureau and added controls for regional characteristics that might influence local patenting productivity. We additionally limit the universe of candidate occupations for the inventive class to those for which engagement in the development, design, or creation of novel ideas by workers is sufficiently important. These changes allow for a more precise identification of the impact of occupational employment on patent production and serve to remove occupations represented in the original inventive class with no obvious connection to patenting. We further extend Wojan, Dotzel, and Low's analysis by implementing a simultaneous equations model of the interrelationship between the composition and productivity of the updated inventive class. Substitutions of alternative subpopulations of potential inventors and contributors to the inventive process (i.e., denominators) for the inventive class allow us to further assess the value added of the updated construct.

This paper is organized as follows. The next section provides a brief review of the relevant literature on regional invention. This is followed by a redefinition of Wojan, Dotzel, and Low's (2015) inventive class using more detailed occupation data. The updated inventive class is then used to standardize and decompose traditional population-denominated patenting rates. Analysis of the interrelationship between the composition and productivity of the inventive class and other subpopulations of knowledge workers provides an empirical evaluation of alternative regional patent indicators. Robustness checks and limitations of the analysis are addressed before concluding with a discussion of the broader implications of this research for regional invention indicators.

Summary of the Literature on Regional Invention

With the transformation from an industrial economy to an innovation economy there is increasing interest in the innovative capacity of economically lagging regions (Rodríguez-Pose and Wilkie 2019; Stephens, Partridge, and Faggian 2013; Usai 2011). Patents per capita have been used to investigate the heterogeneity of the innovation process across regions to assess the viability of extending innovation policy—possibly customized to different regional types—to all areas (Apa et al. 2018). Establishing the construct validity of variables used to measure innovative capacity would appear to be a requisite first step in advancing this policy debate.

Most of the criticism regarding patents per capita as a metric for innovative capacity, defined by Furman, Porter, and Stern at the national level as “the ability of a country to produce and commercialize a flow of innovative technology over the long term” (2002:889), has been directed at the numerator—that is, patents. Carlino and Kerr (2014) argue that patents may be a poor measure of innovative activity because they represent only an initial step toward innovation and are not necessarily exploited in the region they are produced (Feldman and Kogler 2010; Feldman 1994). Furthermore, most patents have little economic impact (Carlino and Kerr 2014), and not all innovation is patentable (Griliches 1990), such as innovation in services and marketing (OECD 2009). Even in the most highly patented industry of manufacturing, trade secrets and lead-time advantages are more frequently used to protect intellectual property (Cohen, Nelson, and Walsh 2000; Shackelford and Jankowski 2021).

In contrast to the numerator, few studies directly challenge the use of population as a denominator for calculating patenting rates. Morel et al. argue that patents per capita “underestimates the innovative capacity of developing countries, because it fails to detect the productivity of highly capable centers of excellence within countries with large populations” (2005:401). The illogicality of including individuals that have no likelihood of participating in a patent application in the patenting rate denominator also holds for developed countries, whose populations include many children, physical laborers, workers in service-providing industries, and retirees that are highly unlikely to patent. Predictions from the spatial division of labor—that is, of low demand for high-skilled workers in rural compared to urban areas—are borne out empirically even within highly patentable sectors (Gibbs, Kusmin, and Cromartie 2005; Wojan 1999; Massey 1995). This further diminishes the value of the patents per capita measure as a means of comparing patenting productivity across regions.

Although Carlino, Chatterjee, and Hunt acknowledge the reasonableness of an inventiveness metric based on occupations traditionally associated with patenting, they argue against this in practice because “it is not obvious what the appropriate set of occupations should be” (2007:404). Rodríguez-Pose and Wilkie (2019) acknowledge the potential problem of per capita normalization in their examination of patenting in lagging regions but find that their population-denominated results are robust to limiting the denominator to the labor force. The select studies that propose or use alternative occupational-derived denominators in place of population when computing patenting rates—such as research and development employees (Fritsch and Slavtchev 2010; Scherer 1965) and scientists and engineers (Furman, Porter, and Stern 2002; Meliciani 2000)—run the risk of being too selective in defining the inventive class and contributing to the potentially misleading result that formal R&D resources are most productive where they are rare. In line with Wojan, Dotzel, and Low’s (2015) study, our goal is to identify a denominator that better captures the variability of local inventive capacity across space.

The inductive technique aims to strike a balance between restricting the patenting rate denominator to a few select occupations with the highest propensity to patent and inundating the denominator with individuals who are highly unlikely to participate in a patent application. We focus on regional inventive capacity, acknowledging Carlino and Kerr’s (2014) argument that patent production is a poor metric for regional innovation in general.¹ Despite their ability to represent

merely one facet of the wider innovation economy, patents remain a powerful predictor of regional productivity growth, low unemployment rates, and the formation of publicly traded firms (Rothwell et al. 2013). Our main hypothesis is that a refined, inductively identified denominator will better capture the geographical variability of local inventive capacity, compared to the more traditional per capita measure, and draw a more accurate picture of invention across space.

Redefining the Inventive Class Using Detailed Occupation Data

Data and methodology

To identify the detailed Census occupations strongly related to patent production, we modify Wojan, Dotzel, and Low’s “hybrid rational/inductive approach” (2015:539), regressing the aggregate number of patents produced in commuting zone (CZ) z during the period 2000–05 ($patents$) on the share of the workforce employed in a selection of detailed Census occupations (equation 1). The hybrid approach allows us to exploit a shared understanding of core occupations in the inventive class, defined by the National Science Foundation’s (NSF)’s classification of science, engineering, and technical (SET) occupations (referred to as “scientists, engineers and technicians” by NSF) (Morrison and Green 2005) without excluding occupations demonstrating a strong association with patenting.² The model is estimated at the commuting zone level to minimize discrepancies between place of work and place of residence when assigning patenting activity to regions, and rural and urban commuting zones are analyzed separately.³

Equation 1

$$Patents_z = \alpha + \beta_1 OccSh_z^1 + \dots + \beta_{19} OccSh_z^{19} + \gamma_1 SETSh_z + \gamma_2 ExclSh_z + \delta_1 PatStock_z + \delta_2 HKSh_z + \delta_3 PopDens_z + \delta_4 WageRentR_z + \delta_5 NatAmen_z + \delta_6 Geo_z + \varepsilon_z$$

We include share of the workforce in SET occupations in each regression ($SETSh$) and, ultimately, all 48 SET occupations as part of our inventive class due to these occupations’ strong a priori relationship with invention. We randomly select an additional 19 non-SET occupation shares ($OccSh$) to include in each of 10,000 separate regressions.⁴ We select from only those non-SET occupations for which engagement in the development, design, or creation of novel ideas by workers is sufficiently important, as described below.

Descriptions of variables included in equation 1, excluding the occupation shares, with associated summary statistics, are provided in [table 1](#). Absent from Wojan, Dotzel, and Low’s (2015) analysis but included in our regressions are 1975–1980 patent stock ($PatStock$), share of working-age population with a bachelor’s degree or higher ($HKSh$), population density ($PopDens$), wage-rental ratio ($WageRentR$), and the Department of Agriculture’s (USDA’s) Economic Research Service (ERS) natural amenity rank ($NatAmen$). These variables are intended to control for conditions affecting knowledge sharing and quality of life in each commuting zone that may influence patenting productivity.

TABLE 1

Description of variables in inventive class regressions, excluding occupation shares

(Descriptive statistics)

Variable name	Variable description	Source	Commuting zones	Mean	Standard deviation	Minimum	Maximum
Patents	Utility patents awarded in commuting zone in years 2000–05 (geolocation based on awardee’s or awardees’ county of application)	U.S. Patent and Trademark Office (USPTO)	Rural	35.16	55.4	0	502.52
			Urban	1,825.01	4,910.38	6.03	5.18E+04
1975–80 patent stock	Utility patents awarded in commuting zone in years 1975–80 (geolocation based on awardee’s/awardees’ county of application)	USPTO	Rural	23.48	82.48	0	1,498.20
			Urban	747	1,910.28	2	1.66E+04
Human capital share	Percentage of working-age population (25–64 years) with at least a bachelor’s degree	Census Bureau, 2000 Census of Population and Housing, Summary File 4 (SF4)	Rural	16.01	5.51	7.6	44.07
			Urban	20.65	6.18	8.64	43.76

TABLE 1

Description of variables in inventive class regressions, excluding occupation shares

(Descriptive statistics)

Variable name	Variable description	Source	Commuting zones	Mean	Standard deviation	Minimum	Maximum
Population density	Commuting zone population divided by land area	Census Bureau, 2000 Census of Population and Housing, SF1	Rural	26.96	26.84	0.51	199.12
			Urban	207.25	466.13	6.5	7,164.24
Natural amenity rank	Mean Economic Research Service (ERS) natural amenity rank, a discrete, county-level, low-to-high amenity index (1–7) "constructed by combining six measures of climate, topography, and water area that reflect environmental qualities most people prefer" (Department of Agriculture 2016), weighted by population of counties in commuting zone	Department of Agriculture Economic Research Service (ERS), 1999	Rural	3.57	1.03	1.46	7
			Urban	3.66	1.08	1.22	7
Wage-rental ratio	Mean ratio of average monthly wage to average monthly rental rate, weighted by population of counties in commuting zone	Census Bureau, 2000 Census of Population and Housing, SF4	Rural	5.24	1.03	3.23	9.42
			Urban	4.21	0.54	2.89	6.18

Note(s):

Equation 1 additionally includes categorical controls for Census region and ERS Rural-Urban Continuum Code of the commuting zone's most urban county.

Source(s):

U.S. Patent and Trademark Office; Census Bureau, 2000 Census of Population and Housing, Summary File 1 and Summary File 4; Department of Agriculture Economic Research Service, 1999.

Our hypothesis is that commuting zones with a history of patenting, as measured by patent stock, are more likely to have institutions in place and an inventive culture that supports patent production. Past discoveries in a given region provide a direct measure of the local knowledge stock that may inform and promulgate later inventions (Furman, Porter, and Stern 2002). By controlling for workforce education, we account for the human capital endowment of commuting zones, which is not necessarily interchangeable with occupational employment. A skilled workforce improves the ability of firms in a region to absorb and develop new knowledge (Cohen and Levinthal 1990). Population density serves as a proxy for agglomeration economies which may promote cooperative invention (Knudsen et al. 2008). Additionally, a number of studies find that in-person interactions play a key role in facilitating the flow of knowledge between collaborators (e.g., McCann and Simonen [2005]; Storper and Venables [2004]). Natural amenities could increase the productivity of inventive workers by driving the location choices of higher-quality workers (Guimarães, Munn, and Woodward 2015). Less speculatively, enhancement of individual creativity due to exposure to natural beauty is now supported by several statistical studies (Pasanen, Neuvonen, and Korpela 2018; Plambech and Konijnendijk van den Bosch 2015). Amenity-rich areas may also facilitate creative thought processes that are essential to finding the nonobvious solutions that characterize invention. At face value, wage-rental ratio captures cost of living in a commuting zone, but it can also be viewed as a negative proxy for amenities, both natural and man-made (Roback 1982, 1988).

Two sets of categorical variables capturing the Rural-Urban Continuum Code (RUCC) of the commuting zone's most urban county and U.S. Census region, respectively,⁵ are additionally included in equation 1 (represented by Geo).⁶ Table 2 summarizes the land area, population, and regional distribution of the sample's 309 urban commuting zones and 378 rural commuting zones by assigned RUCC.

TABLE 2

Summary of commuting zones in inventive class regressions, by assigned Rural-Urban Continuum Code

(Descriptive statistics)

Rural-Urban Continuum Code (RUCC)	Count	Land area (hundreds of square miles)				Population (thousands)				Distribution by Census region (%)			
		Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Northeast	Midwest	South	West
Urban													
County in metro area of 1,000,000 population or more (RUCC 1)	93	7.74	535.91	48.87	67.56	32.89	16,400.00	1,810.37	2,378.25	15.05	25.81	47.31	11.83
County in metro area of 250,000–1,000,000 population (RUCC 2)	94	15.21	174.28	52.23	37.12	65.83	1,573.10	611.66	309.41	9.57	24.47	51.06	14.89
County in metro area of fewer than 250,000 population (RUCC 3)	122	5.81	307.33	46.05	35.52	65.73	583.25	235	104.11	5.74	27.87	45.9	20.49
Rural													
Urban population of 20,000 or more, adjacent to a metro area (RUCC 4)	56	8.76	311.46	32.78	41.31	32.01	267.29	119.79	53.72	8.93	26.79	50	14.29
Urban population of 20,000 or more, not adjacent to a metro area (RUCC 5)	68	7.8	302.31	50.42	42.35	35.94	281.81	108.09	55.38	1.47	45.59	30.88	22.06
Urban population of 2,500–19,999, adjacent to a metro area (RUCC 6)	97	5.44	125.3	30.28	23.21	10.35	242.06	64.92	39.73	1.03	37.11	46.39	15.46
Urban population of 2,500–19,999, not adjacent to a metro area (RUCC 7)	118	0.48	211.78	43.61	34.01	7.42	158.43	36.36	26.51	4.24	45.76	21.19	28.81
Completely rural or less than 2,500 urban population, adjacent to a metro area (RUCC 8)	10	5.34	50.42	24.89	13.07	4.19	35.95	16.82	10.76	0	40	40	20

TABLE 2

Summary of commuting zones in inventive class regressions, by assigned Rural-Urban Continuum Code

(Descriptive statistics)

Rural-Urban Continuum Code (RUCC)	Count	Land area (hundreds of square miles)				Population (thousands)				Distribution by Census region (%)			
		Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Northeast	Midwest	South	West
Completely rural or less than 2,500 urban population, not adjacent to a metro area (RUCC 9)	29	1.75	69.28	27.9	17.2	1.86	59.68	7.9	10.51	0	51.72	10.34	37.93

Note(s):

Each commuting zone (CZ) has been assigned the Economic Research Service (ERS) RUCC (defined at the county level) associated with the CZ's most urban county. All Hawaii and Alaskan CZs (including the Alaskan portion of CZ 171), as well as CZs 654, 646, 680, and 685, are excluded from this analysis due to missing values for one or more variables in equation 1.

Source(s):

Census Bureau, 2000 Census of Population and Housing.

To define the two patenting measures, we rely on a cross-section of an annual data set of all utility patents granted by the U.S. Patent and Trademark Office (USPTO),⁷ which geolocates inventors to their county of residence at the time of application.⁸ Although these USPTO data are available annually for years 1975–2010, reliance on a special Equal Employment Opportunity (EEO) tabulation of Census 2000 occupational data to define the occupational measures precludes a multiyear analysis. We aggregate patent data for 6 years to generate *Patents* and *PatStock* to minimize cases of nonexistent and low patent production in commuting zones. For each commuting zone, *Patents* represents the aggregate of utility patents awarded in years 2000–05, and *PatStock* represents the aggregate of utility patents awarded in years 1975–80. Employing a 6-year aggregate for our dependent variable also accounts for the time lag between patent application and granting—which is, on average, 2 years (Hall, Jaffe, and Trajtenberg 2001).

Remaining variables in equation 1 are generated based on data from the Department of Agriculture's (USDA's) ERS and the Census Bureau. All occupation share measures are based on a special EEO county-level tabulation of Census 2000 occupational data. Following Furman, Porter, and Stern (2002), the use of occupation data in our analysis allows us to correct for distortions caused by variability in the size of dependent population across regions. Because occupation data for subsequent years are not available to us, the analysis is cross-sectional in nature. In a departure from Wojan, Dotzel, and Low's (2015) study, the analysis is additionally restricted to the contiguous United States because ERS does not provide natural amenity metrics for Alaska and Hawaii.

At the most detailed level, the Census 2000 Occupational Classification System provides county-level data on the number of employees in 509 occupations (Fronczek and Johnson 2003). Our analysis excludes the four military-specific Census occupations as well as legislators, postmasters and mail superintendents, and judges, magistrates, and other judicial workers because data were not provided by Census for these occupations. Of the remaining 502 occupations, 454 do not belong to the group of SET occupations used by NSF to track advancements in the innovative and inventive economy (defined as the non-SET occupations). Differing from Wojan, Dotzel, and Low (2015), only those non-SET occupations with Occupational Information Network (O*NET) Thinking Creatively (TC) "Importance" and "Level" ratings that exceed the minimum ratings across SET occupations—1.2 and 1, respectively, both for "agricultural food science technicians"—are included in the random selection procedure.⁹

The O*NET database, sponsored by the Department of Labor’s Employment and Training Administration, is the product of nationwide survey of workers from a broad set of occupations. Each occupation in the O*NET database is associated with a set of descriptors that “defines the key features of [the] occupation as a standardized, measurable set of variables” (O*NET Resource Center 2017). O*NET provides data on 227 descriptors across six domains, including “work activities,” and, within this domain, “mental processes.” O*NET’s TC value describes one such mental process and is attributed to occupations that require workers to “develop..., design..., or creat[e] new applications, ideas, relationships, systems, or products, including artistic contributions” as part of their work activities (O*NET OnLine 2017b). Because O*NET uses the Standard Occupational Classification (SOC) System to classify occupations, it was necessary to match each three-digit Census occupation to its six-digit SOC equivalent occupation before assigning TC values. A detailed description of our Census-SOC matching methodology is available upon request.

After completing the match of the Census occupations to the SOC occupations, each Census occupations was then matched to its TC value based on archived data from O*NET OnLine, beginning with the 3.0 database, published in August 2000. If a match was not made using the 3.0 database (7% of cases), Census occupations were then matched to the 3.1 database values. Unmatched occupations were subsequently matched to TC values from the O*NET databases in chronological order, ending with database 20.3, published in April 2016.

Based on our criteria that considered non-SET occupations should have TC Importance and Level ratings at least as great as minimum ratings across SET occupations,¹⁰ 300 of the 454 non-SET occupations remain in the pool of selected occupations in the analysis.¹¹ Following each regression, we update a collection of count variables, which record instances of inclusion for each occupation share as well as whether each occupation share coefficient is positive and significant at the 5% significance level. These measures allow us to calculate the percentage of time that an occupation share effect is positive and significant in the iterative regression analysis for rural and urban samples. To mitigate omitted variable bias, share of the workforce employed in a considered non-SET occupation for which an individual occupation share is not included is captured by the *ExclSh* variable in each run of the model.

Our inventive subset inclusion criteria for the non-SET occupations follow from Wojan et al.’s study (2015): those occupations associated with coefficients that are positive and significant in at least 75% of their regressions in the metro or nonmetro analysis are characterized as inventive.¹²

Discussion of results

Of the 300 non-SET occupations included in the analysis, 11 are identified as inventive, that is, consistently associated with positive, significant coefficients (see [table 3](#)). Occupations that are strongly associated with patenting in both urban and rural commuting zones include the collection of SET occupations and also marketing managers. The coefficient estimate for engineering managers was significant in 60% of the rural equations in which it appeared and in 100% of urban equations. Occupations with a strong association to patenting in urban commuting zones include market and survey researchers, designers and technical writers, and electronics assemblers—a production occupation. Occupations with a strong association to patenting in rural commuting zones include all the remaining production occupations.

TABLE 3

Inventive occupations

(Percent positive and significant coefficients in iterative estimation of equation 1)

Occupation	Census code(s)	Rural CZs	Urban CZs
Science, engineering, and technical occupations	100–76, 190–96	99.95	89.12
Management occupations			
Marketing and sales managers	5	96.77	99.68
Engineering managers	30	60	100
Life, physical, and social science occupations			
Market and survey researchers	181	0	99.31

TABLE 3

Inventive occupations

(Percent positive and significant coefficients in iterative estimation of equation 1)

Occupation	Census code(s)	Rural CZs	Urban CZs
Arts, design, entertainment, sports, and media occupations			
Designers	263	3.48	97.63
Technical writers	284	14.52	100
Production occupations			
Electrical, electronics, and electromechanical assemblers	772	0	100
Computer control programmers and operators	790	90.21	0
Machinists	803	99.01	0
Model makers and patternmakers, metal and plastic	806	100	0
Tool and die makers	813	100	0
Semiconductor processors	884	100	0.8

CZ = commuting zone.

Note(s):

Summaries of coefficients for the iterative regression analysis are available in Dotzel (2017:165–70).

Source(s):Dotzel K, 2017, *Three Essays on Human Capital and Innovation in the United States*, PhD dissertation, Graduate School of The Ohio State University.

Several occupations found by Wojan et al. (2015) to be consistently associated with patenting in nonmetro commuting zones are not represented in our results. A number of these exclusions (e.g., “entertainers and performers,” “postsecondary teachers”) are likely due to our added controls for Census region and human capital stock: “actors” and “producers and directors,” suboccupations of “entertainers and performers,” are highly concentrated in the West Census region, while “postsecondary teachers” are concentrated in commuting zones with a high percentage of workers with bachelor’s degrees. “Printing workers” and “customer service representatives,”¹³ occupations not traditionally associated with patent production, are additionally absent from the updated inventive class. “Marketing and sales managers,” “market and survey researchers,” and “technical writers” represent new additions compared to the 2015 study.¹⁴ In general, it seems that the modifications made to the previous analysis are effective in removing spurious occupations with no discernible connection to patenting.

Table 4 compares patenting rates across commuting zones containing a global city;¹⁵ these zones are characterized by their “availability of advanced producer services essential for the global coordination of activities by multinational corporations” (Wojan et al. 2015:549). Average absolute value of the difference in patents per inventive class member rank and patents per capita rank for global city commuting zones is larger for the updated inventive class (2.3) compared to Wojan et al. (2015) (1.4). In line with the trend recognized by Wojan and colleagues (2015), commuting zones specializing in media or finance or containing high-amenity cities typically regarded as tourist and/or retirement destinations—including the cities of Los Angeles, Miami, New York, and Orlando—perform better when commuting zones are ranked by patents per inventive class member than when ranked by patents per capita. These cities additionally fall within the bottom five cities when ranked by inventive class employment share, suggesting that they are particularly disadvantaged by their small inventive class populations.

TABLE 4

Patenting statistics for commuting zones containing global cities

(Alternative patenting rates)

Patents per capita rank	Commuting zone	Patents per capita	Patents per inventive class member	Patents per inventive class member rank	Difference in ranks	Difference in ranks, summary occupations ^a	Inventive class employment share
1	San Jose, CA	0.02165	0.23572	1	0	0	0.09187
2	San Francisco, CA	0.00614	0.10516	4	-2	-2	0.05835
3	Portland, OR	0.00538	0.10776	3	0	1	0.04996
4	Minneapolis, MN	0.00523	0.08835	6	-2	2	0.05917
5	Raleigh, NC	0.00518	0.0843	7	-2	-1	0.06144
6	Seattle, WA	0.00514	0.09268	5	1	0	0.05541
7	San Diego, CA	0.00491	0.11064	2	5	1	0.04442
8	Boston, MA	0.00467	0.08174	8	0	-1	0.05713
9	Denver, CO	0.00315	0.05117	17	-8	-2	0.06149
10	Detroit, MI	0.00312	0.06302	9	1	1	0.04957
11	Dallas, TX	0.00309	0.06241	10	1	-1	0.04951
12	Philadelphia, PA	0.00246	0.05968	13	-1	-2	0.0412
13	Phoenix, AZ	0.00241	0.06188	12	1	0	0.0389
14	Houston, TX	0.00233	0.05394	15	-1	-2	0.04327
15	Cincinnati, OH	0.00232	0.0538	16	-1	1	0.04316
16	Cleveland, OH	0.00232	0.05831	14	2	2	0.03979
17	Milwaukee, WI	0.00228	0.0496	18	-1	1	0.04601
18	Chicago, IL	0.00202	0.04762	19	-1	-1	0.04235
19	Los Angeles, CA	0.00201	0.06239	11	8	3	0.0322
20	Atlanta, GA	0.00198	0.03976	20	0	0	0.04977
21	Washington, DC	0.00188	0.02724	29	-8	-4	0.06913
22	Baltimore, MD	0.00156	0.03353	25	-3	-4	0.04647
23	St. Louis, MO	0.00147	0.03638	22	1	1	0.04043
24	Kansas City, MO	0.00147	0.03402	24	0	2	0.04314
25	Columbus, OH	0.0013	0.03069	27	-2	1	0.04239
26	Orlando, FL	0.00127	0.03581	23	3	-1	0.03541
27	Charlotte, NC	0.00098	0.02624	30	-3	0	0.03734
28	Tampa, FL	0.00095	0.03049	28	0	1	0.03115
29	Miami, FL	0.00088	0.03737	21	8	3	0.02366
30	New York, NY	0.00087	0.03199	26	4	1	0.02723

^a See Wojan TR, Dotzel KR, Low SA, 2015, Decomposing Regional Patenting Rates: How the Composition Factor Confounds the Rate Factor, *Regional Studies, Regional Science* 2(1):535–51.

Note(s):

Following Wojan, Dotzel, and Low (2015), the Aleutians West Census Area, AK, is omitted from the Seattle, WA, commuting zone. Difference in ranks column denotes the change in rank, when global city commuting zones are ranked by patents per inventive class member, between Wojan, Dotzel, and Low's (2015) study and our updated analysis.

Source(s):

U.S. Patent and Trademark Office; Census Bureau, special tabulations (2015) of the 2000 Census.

Standardization and Decomposition Analysis Using Newly Defined Inventive Class

A still underrecognized weakness of existing studies of regional invention is their general lack of acknowledgement of differences in the composition of inventive populations across space. In the field of demography, it would be unprecedented to base conclusions regarding regional fertility on a rate (e.g., number of live births divided by total population) that does not consider the size of the region's childbearing population. As shown by Wojan et al. (2015), tools of standardization and decomposition, summarized by Das Gupta (1993) and traditionally applied in demography and other social science disciplines, can be extended to the topic of invention using our newly defined inventive class.¹⁶ Patents per capita for each region can be decomposed as the product of share of total population in the inventive class, known as the *compositional factor*, and patents produced per inventive class member, known as the *rate factor* (RF). This decomposition allows for standardization across compositional and RFs, that is, what observed patenting rates would look like if compositional factors—or alternatively, RFs—were identical across regions. In addition, the decomposition answers to what extent we can attribute differences in observed patenting rates across regions to variation in each of these factors.

Following Wojan et al. (2015),¹⁷ we first investigate how variation in population growth rates impacts the two factors' contribution to differences in observed patenting rates. We do this by separating commuting zones that contain a global city into two groups: those ranked in the top 50% of commuting zones based on their population growth rate between 1975 and 2000, and those ranked in the bottom 50%. We then apply Das Gupta's (1993) standardization and decomposition methodology for the two-factor, two-population case.

Results calculated using the updated inventive class in [table 5](#), defined using the detailed Census occupations in [table 3](#), mirror those based on the 2015 inventive class, with slight differences in magnitude of rates and percent distribution of effects. The standardization of factors calculates the per capita patenting rate that would have been observed if either the inventive class rate or inventive class composition were expressed as the average across both high-growth and low-growth cities. For example, the RF standardization demonstrates that if both groups had the same average patenting rate among inventive class members, low-growth global cities would have higher per capita patenting rates than high-growth global cities (0.0031 vs. 0.0029). Differences in the magnitudes of factors across studies suggest a smaller and more productive inventive class for global cities in the updated analysis.¹⁸

The observed, population-denominated patenting rate (i.e., patents per capita) for commuting zones containing high-growth global cities is 31% higher than the rate for commuting zones with low-growth global cities. Results of the decomposition analysis tell us that 126% of the difference in patents per capita rates across the defined populations is driven by disparities in inventive class patenting productivity across regions, a smaller percentage than indicated by Wojan et al.'s (2015) results.¹⁹ While the observed patenting rate for high-growth global city commuting zones is highest, if inventive class productivity were consistent between the two populations, the patenting rate of low-growth global cities would dominate. The decomposition results also tell us that the high-growth population suffers based on its inventive class composition. If share of population in the inventive class were identical across groups, the gap between the groups' patenting rates would increase. Nonetheless, the compositional disadvantage of high-growth global city commuting zones is more than offset by their productivity advantage.

TABLE 5

Comparison of standardization and decomposition of patenting rates for global city commuting zones based on population growth rate

(Patenting rates)

Patenting rates	Summary occupations ^a				Detailed occupations			
	Standardization of patenting rates		Decomposition of effects		Standardization of patenting rates		Decomposition of effects	
	High growth	Low growth	Effects (High-low)	Percent distribution of effects	High growth	Low growth	Effects (High-low)	Percent distribution of effects
Rate factor (RF)—Standardized	0.00289	0.00312	-0.0002	-28.96	0.0029	0.0031	-0.0002	-25.91
Compositional factor (CF)—Standardized	0.00351	0.0025	0.001	128.96	0.0035	0.00251	0.001	125.91
Observed	0.00338	0.00259			0.00338	0.00259		

^a See Wojan TR, Dotzel KR, Low SA, 2015, Decomposing Regional Patenting Rates: How the Composition Factor Confounds the Rate Factor, *Regional Studies, Regional Science* 2(1):535–51.

Note(s):

RF is patents per inventive class member, and CF is inventive class as a share of total commuting zone population. Following Wojan, Dotzel, and Low (2015), Aleutians West Census Area, AK, is omitted from the Seattle, WA, commuting zone.

Source(s):

U.S. Patent and Trademark Office; Census Bureau, special tabulations (2015) of the 2000 Census.

Next, we examine how patenting rates differ between populations defined based on level of urbanization. Following Wojan et al. (2015), we divide commuting zones into three groups—rural; urban, without a global city (UWGC); and urban, containing a global city (UCGC).²⁰ For this step in the analysis, we apply Das Gupta’s two-factor, three-population standardization and decomposition methodology, which ensures that there is “only one standardized rate for a population when standardization is done with respect to the same factor” (1993:97) and that effects are internally consistent.²¹

The results for our two-factor, three-population case based on level of urbanization are presented in [table 6a](#) and [table 6b](#). Our results indicate that for each region-type pair, differences in the composition of inventive populations across regions are responsible for 50%–55%—that is, the majority—of the difference in population-denominated patenting rates. This contrasts with the decomposition results of Wojan et al. (2015), which identify productivity differences as the main driver of differences in observed population-denominated patenting rates for each region-type pair. While observed patents per capita rates indicate that global cities are approximately six times more productive than rural areas in producing patents, when inventive class population share is held constant across the two populations, global cities are only twice as productive. This provides compelling evidence that the composition of inventive populations across regions must be considered by researchers if meaningful conclusions are to be made concerning the inventive capacity of rural and urban regions.

TABLE 6a

Standardization of patenting rates for commuting zones based on level of urbanization

(Patenting rates)

Patenting rates	Summary occupations ^a			Detailed occupations		
	Standardization of patenting rates					
	Urban, containing a global city	Urban, without a global city	Rural	Urban, containing a global city	Urban, without a global city	Rural
Rate factor (RF)–Standardized	0.00199	0.00155	0.00121	0.00226	0.0015	0.00096
Compositional factor (CF)–Standardized	0.00246	0.0015	0.0008	0.00216	0.00154	0.00102
Observed	0.00297	0.00158	0.00053	0.00297	0.00159	0.00053

^a See Wojan TR, Dotzel KR, Low SA, 2015, Decomposing Regional Patenting Rates: How the Composition Factor Confounds the Rate Factor, *Regional Studies, Regional Science* 2(1):535–51.

Note(s):

RF is patents per inventive class member, and CF is inventive class as a share of total commuting zone population. In a departure from Wojan, Dotzel, and Low (2015), all Hawaiian and Alaskan commuting zones (including Aleutians West Census Area, AK, part of the Seattle, WA, commuting zone) are omitted. This change results in slight discrepancies in observed patenting rates across studies.

Source(s):

U.S. Patent and Trademark Office; Census Bureau, special tabulations (2015) of the 2000 Census.

TABLE 6b

Decomposition of patenting rates for commuting zones based on level of urbanization

(Rate and composition factors pertaining to patenting)

Comparison of commuting zones	Summary occupations ^a				Detailed occupations			
	Decomposition of effects							
	Effects		Percent distribution of effects		Effects		Percent distribution of effects	
	RF	CF	RF	CF	RF	CF	RF	CF
UCGC vs. UWGC	-0.00095	-0.00044	68.4	31.6	-0.00062	-0.00076	44.68	55.32
UWGC vs. rural	-0.00071	-0.00034	67.59	32.41	-0.00052	-0.00054	49.3	50.7
Rural vs. UCGC	0.00166	0.00078	68.05	31.95	0.00114	0.0013	46.68	53.32

CF = compositional factor; RF = rate factor; UCGC = urban, containing a global city; UWGC = urban, without a global city.

^a See Wojan TR, Dotzel KR, Low SA, 2015, Decomposing Regional Patenting Rates: How the Composition Factor Confounds the Rate Factor, *Regional Studies, Regional Science* 2(1):535–51.

Note(s):

RF is patents per inventive class member, and CF is inventive class as a share of total commuting zone population. In a departure from Wojan, Dotzel, and Low (2015), all Hawaiian and Alaskan commuting zones (including Aleutians West Census Area, AK, part of the Seattle, WA, commuting zone) are omitted. This change results in slight discrepancies in observed patenting rates across studies.

Source(s):

U.S. Patent and Trademark Office; Census Bureau, special tabulations (2015) of the 2000 Census.

Empirical Evaluation of Newly Defined Inventive Class

Two-factor decomposition of the per capita patenting rate makes it clear that continued reliance on the measure will confound our understanding of the true contributors to inventive capacity. In the extreme case, a regional policy to eliminate the social safety net plausibly could be associated with an increase in the per capita patenting rate. However, the two-factor decomposition would correctly identify the cause as an increase in the share of the population in the inventive class as the disadvantaged population is decimated. This hypothetical example calls into question the value of any finding that fails to model both the rate and compositional factors.

Data and methodology

In this exercise, we evaluate the correlates of inventive production in commuting zones and membership in our inductively defined inventive class. Contributors to the inventive process may be drawn to regions with existing inventive populations—and, likewise, support regional inventive productivity through own-invention or the dissemination of knowledge to other inventors in their region (Agrawal, Kapur, and McHale 2008; Thompson and Fox-Kean 2005; Jaffe, Trajtenberg, and Henderson 1993). Since the direction of causality between these two processes is not obvious, a simultaneous equations model is adopted. Generally, each equation in a simultaneous equations system is referred to as a *structural equation*. All dependent variables are assumed to be endogenous to the system, while all other variables are treated as exogenous and are taken to be instruments for the endogenous variables. Following Faggian and McCann (2009) in their study of interregional human capital flows in Great Britain, our simultaneous equations model is estimated using three-stage least squares (3SLS).

To estimate cross-sectional simultaneous equation models, limited or full information methods are available (Greene 2012). The limited information two-stage least squares (2SLS) method is most commonly used but provides inefficient parameter estimates when error terms are correlated across equations, a possibility that we have no theoretical reason to refute a priori in this case. The full-information 3SLS method, developed by Zellner and Thiel (1962), combines the traditional 2SLS procedure with seemingly unrelated regressions. Under 3SLS, the variance-covariance matrix of cross-equation error terms is estimated in the second stage and used to correct coefficient estimates; this represents the deviation from 2SLS. The 3SLS and 2SLS methods produce equivalent results when error terms are uncorrelated across equations.

Data from the Census Bureau, USDA's ERS, Patent and Trademark Office, and Department of Justice's (DOJ's) Uniform Crime Reporting Statistics (DOJ 2006) are used to generate variables used in the analysis. Choice of variables mirrors those selected by Faggian and McCann (2009),²² with a few modifications motivated by differences in data availability and study relevance, as described below. [Table 7](#) includes descriptions of and summary statistics for all considered variables, while pairwise correlation coefficients for these variables are presented in [table 8](#).

TABLE 7

Description of variables in simultaneous equations model—rural and urban commuting zones

(Descriptive statistics)

Variable name	Variable description	Source(s)	Commuting zone	Mean	Standard deviation	Minimum	Maximum
Dependent							
Patents	Utility patents awarded in commuting zone in year 2000 (geolocation based on awardee's or awardees' county of application)	U.S. Patent and Trademark Organization (USPTO)	Rural	35.47	56.1	0	502.52
			Urban	1,867.22	4,968.36	6.03	51,821.97
Inventive class (IC)	Workers in group of identified inventive occupations (in table 3)	Census special tabulation, 2000	Rural	1,168.84	1,188.44	24	9,606.00
			Urban	31,161.69	61,181.13	571	5.28E+05

TABLE 7

Description of variables in simultaneous equations model—rural and urban commuting zones

(Descriptive statistics)

Variable name	Variable description	Source(s)	Commuting zone	Mean	Standard deviation	Minimum	Maximum
Science, engineering, and technical (SET) employment	Workers in Census occupations 100–76 and 190–96	Census special tabulation, 2000	Rural	730.2	725.38	16	6,163.00
			Urban	21,749.28	42,831.45	284	3.41E+05
Creative class (CC)	Workers in McGranahan and Wojan's (2007) "recast" creative class (Florida 2002)	Census special tabulation, 2000	Rural	4,720.46	4,204.45	192	3.33E+04
			Urban	1.01E+05	1.96E+05	2,378.00	1.87E+06
Educated workforce (BA)	Working-age population (25–64 years) with at least a bachelor's degree	Census Bureau, 2000 Census of Population and Housing, Summary File 4 (SF4)	Rural	6,756.82	6,116.37	300	5.22E+04
			Urban	1.38E+05	2.75E+05	3,237.00	2.46E+06
Independent Patents equation							
1975–80 patent stock (PatStock)	Utility patents awarded in commuting zone in years 1975–80 (geolocation based on awardee's or awardees' county of application)	USPTO	Rural	23.88	84.59	0	1,498.20
			Urban	764.36	1,932.52	2	16,561.30
Population density (PopDens)	Commuting zone-level population divided by land area	Census Bureau, 2000 Census of Population and Housing, SF1	Rural	26.29	26.7	0.51	199.12
			Urban	210.67	471.81	6.5	7,164.24
University research expenditures (UniResExp)	Aggregate research expenditures (in millions of dollars) in commuting zone for public and private not-for-profit universities	Integrated Postsecondary Education Data System, 2000	Rural	2.39	12.9	0	127.62
			Urban	73.44	175.81	0	1,488.80
Population equation							
Unemployment rate (UR)	Commuting zone-level unemployment rate	Census SF4, 2000	Rural	5.97	2.46	1.38	15.83
			Urban	5.78	1.6	2.72	12.38
Crime rate (CR)	Crimes committed per thousand persons	Department of Justice, 2000	Rural	27.66	14.36	1.18	126.2
			Urban	41.45	13.88	8.48	90.79
Proximity to urban center (ProxUrbCen)	Mean linear distance in miles from geographic midpoint of county to midpoint of county with population ≥ 250,000, weighted by population of counties in commuting zone	Census 2000 shapefile; Department of Agriculture (USDA) Economic Research Service (ERS), 2000	Rural	137.8	96.74	29.82	584.08
Wage-rental ratio (WageRentR)	Ratio of average monthly wage to average monthly rental rate	Census SF4, 2000	Rural	5.22	1.01	3.23	9.42
			Urban	4.2	0.54	2.89	6.18
Natural amenity rank (NatAmen)	Mean ERS natural amenity rank, a discrete county-level low to high amenity index (1–7) "constructed by combining six measures of climate, topography, and water area that reflect environmental qualities most people prefer" (Department of Agriculture 2016), weighted by population of counties in commuting zone	USDA ERS, 1999	Rural	3.6	1.04	1.46	7
			Urban	3.69	1.07	1.33	7
Location quotient for patent-intensive industries (LQPatInd)	Ratio of commuting zone's share of employment to nation's share of employment in patent-intensive industries	Bureau of Labor Statistics Quarterly Census of Employment and Wages, 1998	Rural	0.71	0.73	0	4.04
			Urban	0.95	0.61	0.04	3.46

Note(s):

Equations 2 and 3 additionally include categorical controls for Census region and ERS Rural-Urban Continuum Code of the commuting zone's most urban county.

Source(s):

U.S. Patent and Trade Organization; Census Bureau, Special Tabulation (2000), Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Education Data System, 2000; Department of Justice, 2000; Department of Agriculture Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998; Florida R, 2002, *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community, and Everyday Life*, New York: Basic Books; McGranahan D, Wojan T, 2007, Recasting the Creative Class to Examine Growth Processes in Rural and Urban Counties. *Regional Studies* 41(2):197–216.

TABLE 8

Association among variables in simultaneous equations model—rural and urban commuting zones

(Pearson correlation coefficients)

Commuting zone and variable name	Inventive class (IC)	Science, engineering, and technical (SET) employment	Creative class (CC)	Educated workforce (BA)	Patents	Unemployment rate (UR)	Wage-rental ratio (WageRentR)	Natural amenity rank (NatAmen)	Crime rate (CR)	Proximity to urban center (ProxUrbCen)	Location quotient for patent-intensive industries (LQPatInd)	1975–80 patent stock (PatStock)	Population density (PopDens)
Rural													
SET	0.978												
CC	0.952	0.957											
BA	0.913	0.932	0.984										
Patents	0.782	0.776	0.722	0.706									
UR	0.044	0.089	0.108	0.124	-0.046								
WageRentR	-0.402	-0.443	-0.467	-0.474	-0.287	-0.455							
NatAmen	-0.125	-0.048	-0.03	0.015	-0.099	0.274	-0.367						
CR	0.194	0.216	0.257	0.259	0.092	0.25	-0.48	0.12					
ProxUrbCen	-0.357	-0.323	-0.344	-0.319	-0.242	-0.033	0.376	-0.051	-0.242				
LQPatInd	0.343	0.251	0.212	0.145	0.286	-0.199	0.029	-0.428	0.032	-0.301			
PatStock	0.371	0.376	0.307	0.297	0.483	-0.033	-0.103	-0.063	0.063	-0.127	0.124		
PopDens	0.564	0.514	0.541	0.505	0.364	0.046	-0.344	-0.117	0.268	-0.497	0.318	0.178	
University research expenditures (UniResExp)	0.326	0.409	0.332	0.352	0.433	0.067	-0.194	0.026	0.031	-0.063	0.007	0.105	0.092
Urban													
SET	0.996												
CC	0.984	0.973											
BA	0.976	0.966	0.996										
Patents	0.833	0.833	0.766	0.755									
UR	-0.095	-0.102	-0.058	-0.049	-0.11								
WageRentR	-0.317	-0.323	-0.331	-0.33	-0.325	-0.233							
NatAmen	0.168	0.173	0.181	0.178	0.25	0.308	-0.613						
CR	0.072	0.073	0.088	0.077	-0.013	0.231	-0.261	0.129					
ProxUrbCen	-0.34	-0.34	-0.331	-0.324	-0.275	0.063	0.222	-0.076	-0.117				
LQPatInd	0.169	0.149	0.131	0.115	0.249	-0.307	0.234	-0.291	-0.107	-0.207			
PatStock	0.899	0.878	0.892	0.891	0.749	-0.04	-0.218	0.073	0.001	-0.279	0.221		
PopDens	0.577	0.565	0.646	0.689	0.352	-0.002	-0.202	-0.003	0.024	-0.261	0.031	0.536	
UniResExp	0.8	0.807	0.786	0.795	0.716	-0.076	-0.324	0.11	0.036	-0.272	0.092	0.68	0.557

Source(s):

U.S. Patent and Trade Organization; Census Bureau, Special Tabulation (2000), Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Education Data System, 2000; Department of Justice, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

The first structural equation (equation 2) estimates the aggregate number of patents produced in commuting zone z during the period 2000–05 (*Patents*) as a function of inventive class population (*IC*), aggregate 1975–80 patent stock (*PatStock*), population density (*PopDens*), wage-rental ratio (*WageRentR*), ERS natural amenity rank (*NatAmen*), university R&D expenditures (*UniResExp*), and a location quotient for patent-intensive industries (*LQPatInd*). As is the case for the iterative regression analysis (equation 1), use of an aggregate patenting measure serves to minimize cases of nonexistent and low patent production in commuting zones and accounts for the time lag between patent application and granting. A commuting zone geography is also similarly adopted to minimize discrepancies between place of work and place of residence when assigning patenting activity to regions.

In the second structural equation (equation 3), commuting zone inventive class population is related to *Patents*, unemployment rate (*UR*), *WageRentR*, *NatAmen*, crime rate (*Crime*), proximity to an urban center (*ProxUrbCen*), and *LQPatInd*. Each structural equation additionally includes controls for ERS RUCC and Census region (in *Geo*).

Equation 2

$$Patents_z = \alpha_0 + \alpha_1 IC_z + \alpha_2 PatStock_z + \alpha_3 PopDens_z + \alpha_4 WageRentR_z + \alpha_5 NatAmen_z + \alpha_6 UniResExp_z + \alpha_7 LQPatInd + \alpha_8 Geo_z + \gamma_z$$

Equation 3

$$IC_z = \beta_0 + \beta_1 Patents_z + \beta_2 UR_z + \beta_3 WageRentR_z + \beta_4 NatAmen_z + \beta_5 Crime_z + \beta_6 ProxUrbCen_z + \beta_7 LQPatInd_z + \beta_8 Geo_z + \varepsilon_z$$

The definition of our location quotient (LQ)—the ratio of the commuting zone’s share of employment to the nation’s share of employment in patent-intensive industries,²³ as determined by the Economics and Statistics Administration and the USPTO (Department of Commerce 2012)—represents a departure from Faggian and McCann (2009), whose location quotient is defined based on employment in the wider manufacturing industry. We include *LQPatInd* in both structural equations because the agglomeration of workers in occupations highly amenable to patenting could concurrently affect the inventive productivity and size of the considered subpopulations. Our addition of historic patent stock to the structural equation for patents follows from equation 1.

The inclusion of a natural amenity measure in both structural equations signifies a second deviation from Faggian and McCann’s (2009) analysis. Initial consideration of favorable climate as a determinant of location choice can be traced to early studies by Graves (1979, 1980) and Carlino and Mills (1987). More recent works explore how natural amenities factor into the location choices of high-skilled workers specifically (Fiore et al. 2015; Whisler et al. 2008; Gottlieb and Joseph 2006). In addition to affecting the composition of the considered subpopulations, natural amenities may promote patent production from these workers by stimulating the creative thought processes essential to invention, as argued for equation 1 in section 3.1 (Pasanen, Neuvonen, and Korpela 2018; Plambech and Konijnendijk van den Bosch 2015). The interpretation of wage-rental ratio as a negative proxy for amenities (Roback 1982, 1988) similarly justifies its addition to equation 2.

The use of university R&D expenditures (*UnivResExp*) in place of the composite university, government, and private R&D expenditure measure used in McCann and Faggian (2009) is a third deviation.²⁴ Data limitations in the United States relative to the European Union necessitate this choice, but *UnivRevExp* may be the critical component of the composite for examining rural patenting as land grant research universities in rural commuting zones may have a large impact on differential patenting rates. Studies of rural innovation (Aryal et al. 2018) and high technology manufacturing location (Woodward, Figueiredo, and Guimarães 2006) provide empirical support for this conjecture. The absence of private R&D is more of a concern in the urban commuting zone equations, where this type of expenditure is concentrated.

Although our primary motivation for this modeling exercise is to identify the correlates of regional inventive capacity, we also intend to assess the value-added of the inventive class construct by substituting three other subpopulations of knowledge workers as dependent variables in equation 3 who may potentially contribute to the patenting process for our inventive class:²⁵ (1) SET workers, which Furman, Porter, and Stern (2002) include (as “scientists and engineers”) in their model of international innovative capacity; (2) Richard Florida’s (2002) creative class (CC), as recast by McGranahan and Wojan (2007); and (3) workers possessing a bachelor’s degree or higher (BA).²⁶ Notably, a strong correlation between each subpopulation pair is visible in [table 8](#), with CC and BA showing the strongest correlation in both rural and urban regions.²⁷ We exclude measures of regional university quality and student density from equation 3 to isolate the impact of human capital on invention to the considered subpopulations of knowledge workers.

Based on the summary statistics in [table 7](#), rural commuting zones produced approximately 35 patents during the period 2000–05, on average, compared to the 1,867 patents produced by each urban commuting zone. Mean populations of the considered groups of knowledge workers for urban commuting zones measured in year 2000 likewise significantly exceed those for rural commuting zones (by factors of 27, 30, 21, and 20 for inventive class, SET employment, CC, and human capital stock, respectively).

Discussion of results

Results for rural commuting zones for each structural equation, are provided in [table 9](#), while results for urban commuting zones are provided in [table 10](#).

TABLE 9

Results for simultaneous equations model—rural commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)		Science, engineering, and technical (SET) employment		Creative class (CC)		At least 4-year college degree (BA)					
	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value				
Patents dependent variable												
IC	0.050	***	<0.001	-	-	-	-	-	-	-	-	-
SET	-	-	-	0.089	***	<0.001	-	-	-	-	-	-
CC	-	-	-	-	-	-	0.020	***	0.003	-	-	-
BA	-	-	-	-	-	-	-	-	-	0.016	**	0.011
1975–80 patent stock (PatStock)	0.082	**	0.035	0.040		0.392	0.054		0.259	0.026		0.673
Population density (PopDens)	0.057		0.759	0.037		0.842	-0.058		0.852	-0.063		0.858
Wage-rental ratio (WageRentR)	2.961		0.245	3.926		0.163	7.060	*	0.052	8.093	*	0.066
Natural amenity rank (NatAmen)	2.392		0.372	2.084		0.467	-0.634		0.853	-3.421		0.421
University research expenditures (UniResExp)	0.498	**	0.046	0.227		0.569	0.261		0.533	0.067		0.913
Location quotient for patent-intensive industries (LQPatInd)	-3.091		0.518	1.980		0.635	4.279		0.292	9.962	**	0.012
Root mean square error (RMSE)	33.334			35.753			45.747			52.211		
Chi-squared	722.450			700.830			557.750			546.140		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.613			3.622			3.579			3.599		
Population subset dependent variable												
Patents	13.088	***	<0.001	9.366	***	<0.001	40.221	***	<0.001	59.599	***	<0.001
Unemployment rate (UR)	-8.340		0.377	-2.705		0.520	-20.520		0.466	-13.743		0.697
WageRentR	-96.384	*	0.060	-54.985	*	0.090	-438.359	**	0.024	-579.159	**	0.044
NatAmen	-51.772		0.309	-24.166		0.452	26.575		0.891	215.555		0.450

TABLE 9

Results for simultaneous equations model—rural commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset							
	Inventive class (IC)		Science, engineering, and technical (SET) employment		Creative class (CC)		At least 4-year college degree (BA)	
	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value
Crime	-2.630	0.325	-0.741	0.661	-2.581	0.798	-0.594	0.968
Proximity to urban center (ProxUrbCen)	-0.235	0.329	-0.033	0.713	-0.335	0.609	-0.165	0.808
LQPatInd	158.979	*** 0.004	3.505	0.919	-57.902	0.780	-554.310	* 0.070
RMSE	593.498		377.385		2,266.630		3,348.046	
Chi-squared	920.386		876.182		751.696		718.792	
p-value	<0.0001		<0.0001		<0.0001		<0.0001	
Mean VIF	3.357		3.357		3.357		3.357	

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.**Note(s):**

Structural equation estimates are based on 358 observations. Controls for Census region and Rural-Urban Continuum Code are included in each regression.

Source(s):Dotzel K, 2017, *Three Essays on Human Capital and Innovation in the United States*, PhD Dissertation, Graduate School of The Ohio State University, p. 108.

TABLE 10

Results for simultaneous equations model—urban commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset							
	Inventive class (IC)		Science, engineering, and technical (SET) employment		Creative class (CC)		At least 4-year college degree (BA)	
	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value
Patents dependent variable								
IC	0.071	** 0.029	-	-	-	-	-	-
SET	-	-	0.089	** 0.025	-	-	-	-
CC	-	-	-	-	0.023	- 0.103	-	-
BA	-	-	-	-	-	-	0.021	* 0.066
1975–80 patent stock (PatStock)	-0.067	0.919	0.119	0.824	-0.092	0.918	-0.469	0.628
Population density (PopDens)	-0.312	0.294	-0.223	0.323	-0.794	0.444	-1.629	0.304
Wage-rental ratio (WageRentR)	108.651	0.767	117.404	0.746	224.921	0.595	231.237	0.570
Natural amenity rank (NatAmen)	572.904	** 0.017	675.247	*** 0.004	481.491	0.102	397.441	0.216
University research expenditures (UniResExp)	0.507	0.879	1.333	0.678	1.322	0.717	-0.262	0.950

TABLE 10

Results for simultaneous equations model—urban commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)			Science, engineering, and technical (SET) employment			Creative class (CC)			At least 4-year college degree (BA)		
	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value
Location quotient for patent-intensive industries (LQPatInd)	1,268.640	***	<0.001	1,381.611	***	<0.001	1,475.747	***	<0.001	1,630.737	***	<0.001
Root mean square error (RMSE)	2,519.018			2,485.737			2,937.586			3,087.723		
Chi-squared	1,142.140			1,121.990			974.000			966.720		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.618			3.374			3.567			3.749		
Population subset dependent variable												
Patents	14.454	***	<0.001	10.058	***	<0.001	44.844	***	<0.001	62.692	***	<0.001
Unemployment rate (UR)	331.768		0.818	-107.580		0.915	1651.611		0.748	5258.581		0.488
WageRentR	-1,511.598		0.781	-1,417.036		0.706	-11,720.238		0.563	-16,629.983		0.564
NatAmen	-8,179.447	**	0.023	-6,659.816	***	0.008	-21,248.347		0.110	-29,851.854		0.116
Crime	18.125		0.852	22.589		0.715	53.358		0.907	-64.602		0.920
Proximity to urban center (ProxUrbCen)	-0.843		0.973	-4.343		0.795	-2.246		0.981	15.117		0.909
LQPatInd	-18,047.43	***	-1.88E-05	-13,980.73	***	-1.74E-06	-64,623.46	***	-3.06E-05	-95,270.52	***	-1.65E-05
RMSE	36,915.877			25,499.627			137,000.000			194,000.000		
Chi-squared	751.012			759.527			534.444			508.216		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	2.354			2.354			2.354			2.354		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.**Note(s):**

Structural equation estimates are based on 301 observations. Controls for Census region and Rural-Urban Continuum Code are included in each regression.

Source(s):Dotzel K, 2017, *Three Essays on Human Capital and Innovation in the United States*, PhD Dissertation, Graduate School of The Ohio State University, p. 112.

For rural commuting zones, results for the first structural equation indicate that membership in each of the four considered classes of knowledge workers positively impacts patent production. Size of the SET workforce has the largest estimated effect on invention: for every 11 additional SET workers to a rural commuting zone, one patent is produced during the 6-year period of interest. Each additional SET worker's contribution to patenting is approximately twice that of an additional worker in the inventive class: one patent is produced for every 20 additional IC workers. From a precision perspective, the IC measure in the rural patents equation is statistically more powerful than the SET measure; the p-value for the SET point estimate is approximately three times that of the IC point estimate (p-values 0.000806 and 0.000238, not shown). Workers employed in the creative class and workers possessing a bachelor's degree have the smallest estimated

impact on patent production: 50 and 63 additional creative class members and educated workers, respectively, are associated with the production of one patent. The much higher *p*-values for coefficients on both *CC* and *BA* in their respective regressions, compared to those for *IC* and *SET*, confirm that both measures include a good deal of information that is not relevant to patent production.

Although size of the *SET* workforce appears to dominate as a predictor of invention in rural regions, results for the second structural equation indicate that inventive output may have a significant role to play in supporting other groups of knowledge workers that a sole focus on *SET* workers obscures. For the rural sample, the production of an additional patent increases estimated employment in *SET* occupations by 9, inventive class membership by 13, creative class membership by 40, and educated workforce size by 60. Our results seem to confirm the existence of an interrelationship between patent production and membership in our updated inventive class.

Wage-rental ratio, which can be interpreted as a negative proxy for amenities (Roback 1982, 1988), is positively associated with patenting when the creative class or workers with a bachelor's degree are the population of interest. Estimated effects for *LQPatInd* across specifications may provide insight into these results. The constructed location quotient for patent-intensive industries is associated with a significant coefficient in the *BA* patents specification, suggesting that the *WageRentR* variable may be picking up a tendency for manufacturing industries—and, more specifically, inventive industries—to concentrate in low-amenity commuting zones. The coefficient on *LQPatInd* is similarly positive (and relatively large in magnitude) in the creative class patents equation, though not precisely estimated. Other explanatory variables associated with significant effects in the first structural equation include *PatStock* and *UniResExp* for the inventive class specification. Insignificance of *UniResExp* estimates in the *SET*, *CC*, and *BA* patents results is notable given the policy interest in public R&D funding.

Based on the rural results for the second structural equation, *WageRentR* negatively impacts size of all considered populations of knowledge workers. This could be reflective of a willingness of these workers to accept lower wages or higher rents in exchange for access to amenities (e.g., dining, shopping, entertainment). The apparent ability of the inventive class to better account for the contribution of rural workers in patent-intensive industries, as evidenced by the positive and significant coefficient on *LQPatInd* in the second structural equation, compared to the alternative subpopulations of knowledge workers highlights its potential value to studies of rural invention. Analysis of urban commuting zones (table 10) discussed below points to regional variation in the inventive process and suggest the value of examining contributions from a wider spectrum of knowledge workers to get a complete picture of patent production.

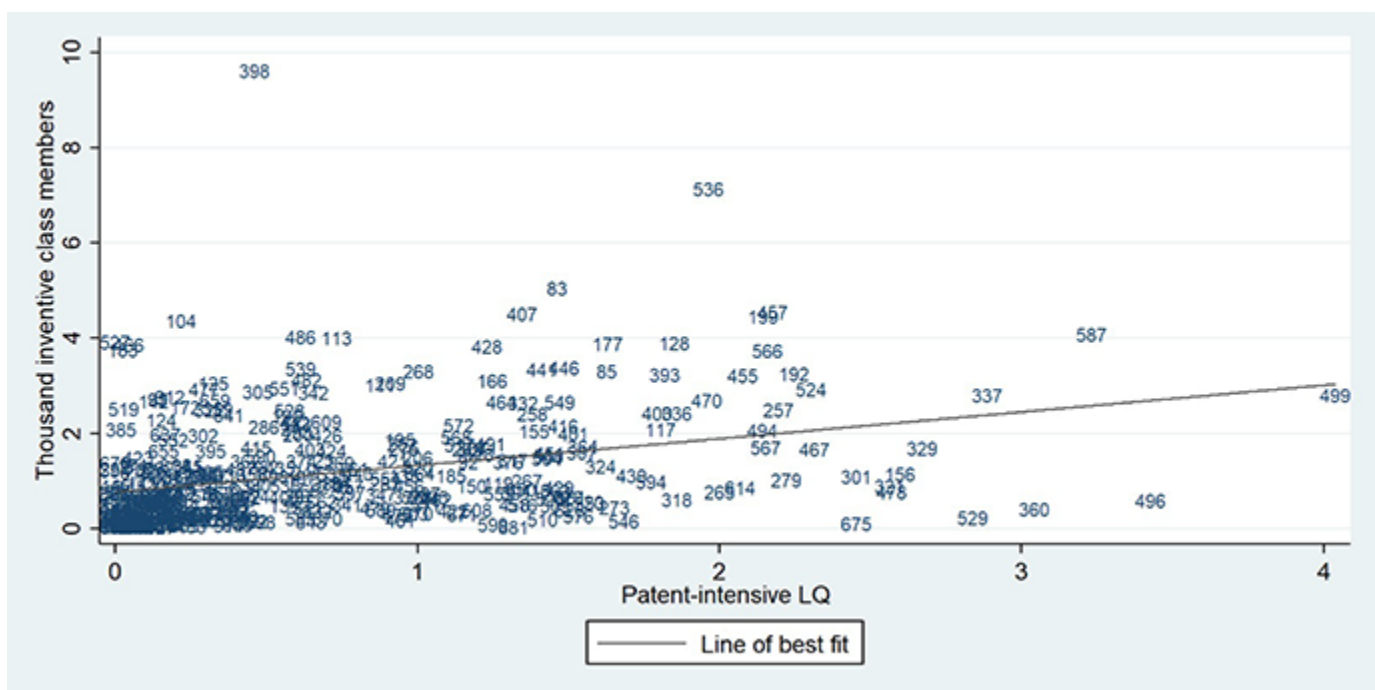
As is the case for rural commuting zones, the subset of workers employed in *SET* occupations has the greatest impact on successful invention in urban commuting zones. However, the associated coefficient on *SET* in table 10 is only 25% larger than the coefficient on *IC* when the inventive class is substituted for *SET* workers as the population of interest (compared to the approximate 1:2 relationship that exists in rural commuting zones). In contrast to the rural results, the *SET* effect is more precisely estimated than the *IC* effect in the urban case. The magnitude of effects associated with workers employed in the creative class and workers possessing a bachelor's degree are approximately one-third and one-fourth, respectively, of those for the inventive class and *SET* workforce. However, the estimated impact of creative class membership on patent production in urban regions is not precisely estimated. It is estimated that additions of 14, 11, and 48 workers to the inventive class, *SET* workforce, and educated workforce, respectively (and individually), contribute to the production of one patent in urban commuting zones for the period of interest.

Based on the estimated coefficients from the second structural equation, the production of an additional patent is associated with the addition of 10 workers employed in *SET* occupations, 14 inventive class members, 45 creative class members, and 63 educated workers to an urban commuting zone. A positive association between ERS natural amenity rank and patent production is observed in the *IC* and *SET* results, while the estimated impact of *LQPatInd* in the first structural equation is large and consistently positive for all considered subpopulations of knowledge workers in the urban case.

The large, negative coefficients on *LQPatInd* across specifications in the second structural equation are initially perplexing. Correlation between *LQPatInd* and *IC* is notably low in urban regions (0.17) relative to rural regions (0.34). When the urban sample is further divided into commuting zones that contain and do not contain a global city, associated correlation coefficients are 0.37 for UCGC commuting zones and 0.04 for UWGC commuting zones. Scatter plots of inventive class membership by patent-intensive LQ are displayed as [figure 1](#), [figure 2](#), and [figure 3](#) for rural, UWGC, and UCGC commuting zones, respectively. In each figure, commuting zone IDs from year 2000 are used in lieu of traditional scatter plot markers. Based on [figure 3](#), the positive trend observed for urban commuting zones containing a global city appears to be driven by the commuting zones containing Chicago, IL (identified by commuting zone ID 58), San Jose, CA (218), and Los Angeles, CA (323). When these commuting zones are excluded from the group of UCGCs, correlation between *LQPatInd* and *IC* falls to -0.33.

FIGURE 1

Inventive class membership, by patent-intensive location quotient—rural commuting zones: 2000



Note(s):

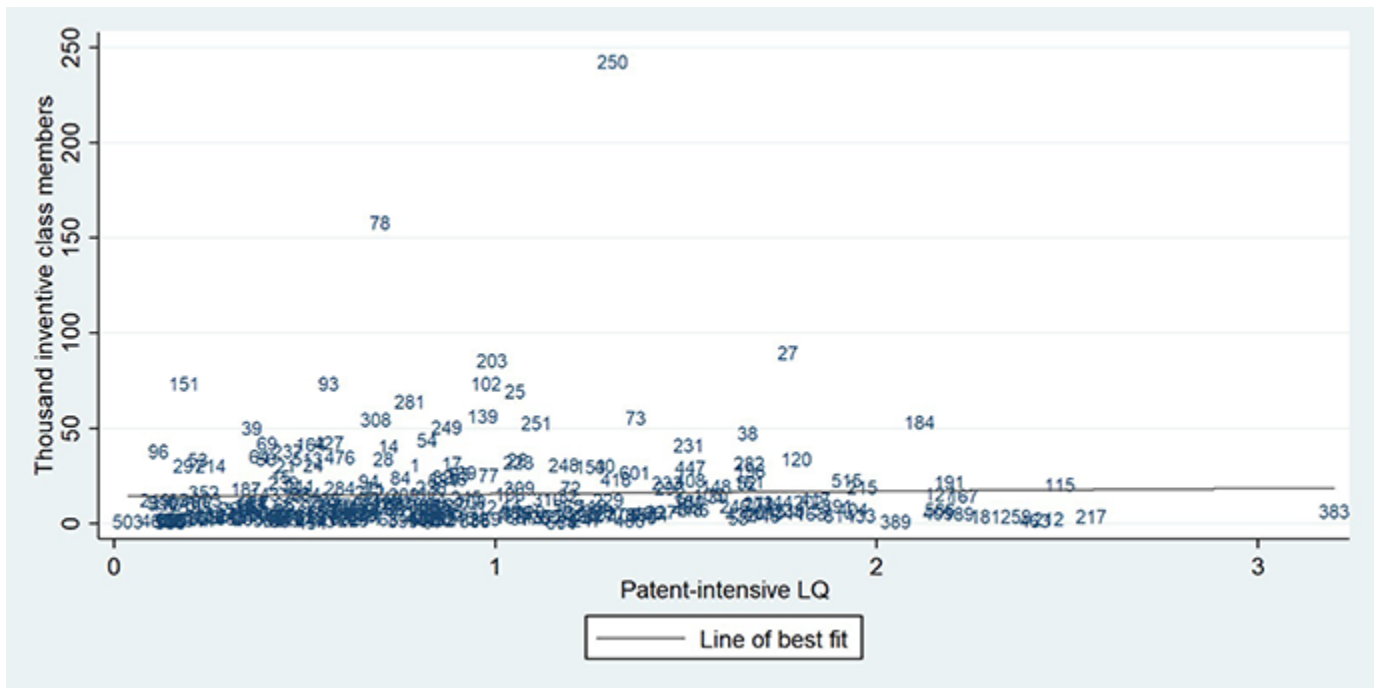
The Economic Research Service (ERS) 2000 commuting zone (CZ) IDs identified in figure (available at <https://ers.usda.gov/data-products/commuting-zones-and-labor-market-areas>). The 2000 ERS CZs are constructed using intercounty commuter flow data from the 2000 Census of Population. No naming protocol for CZs was developed, so the Commuting zone description names a statistical area contained in the CZ. Information on the constituent counties making up each Commuting zone ID is available at the website along with documentation of how the CZs were constructed. The group of patent-intensive industries is characterized by the above-average utility patent intensities (i.e., patent-to-employee ratios) of its industries. Select three- and four-digit industries within the following North American Industry Classification System subsectors are included: computer and electronic product manufacturing; chemical manufacturing; electrical equipment, appliance, and component manufacturing; machinery manufacturing; and miscellaneous manufacturing (Department of Commerce 2012). A location quotient of more than 1.000 indicates a CZ has a higher share of patent-intensive industry employment than the nation as a whole.

Source(s):

Census Bureau, 2000 Census Special Tabulation; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998; Department of Commerce, 2012, *Intellectual Property and the U.S. Economy: Industries in Focus*, available at https://www.uspto.gov/sites/default/files/news/publications/IP_Report_March_2012.pdf.

FIGURE 2

Inventive class membership, by patent-intensive location quotient—urban commuting zones without a global city: 2000

**Note(s):**

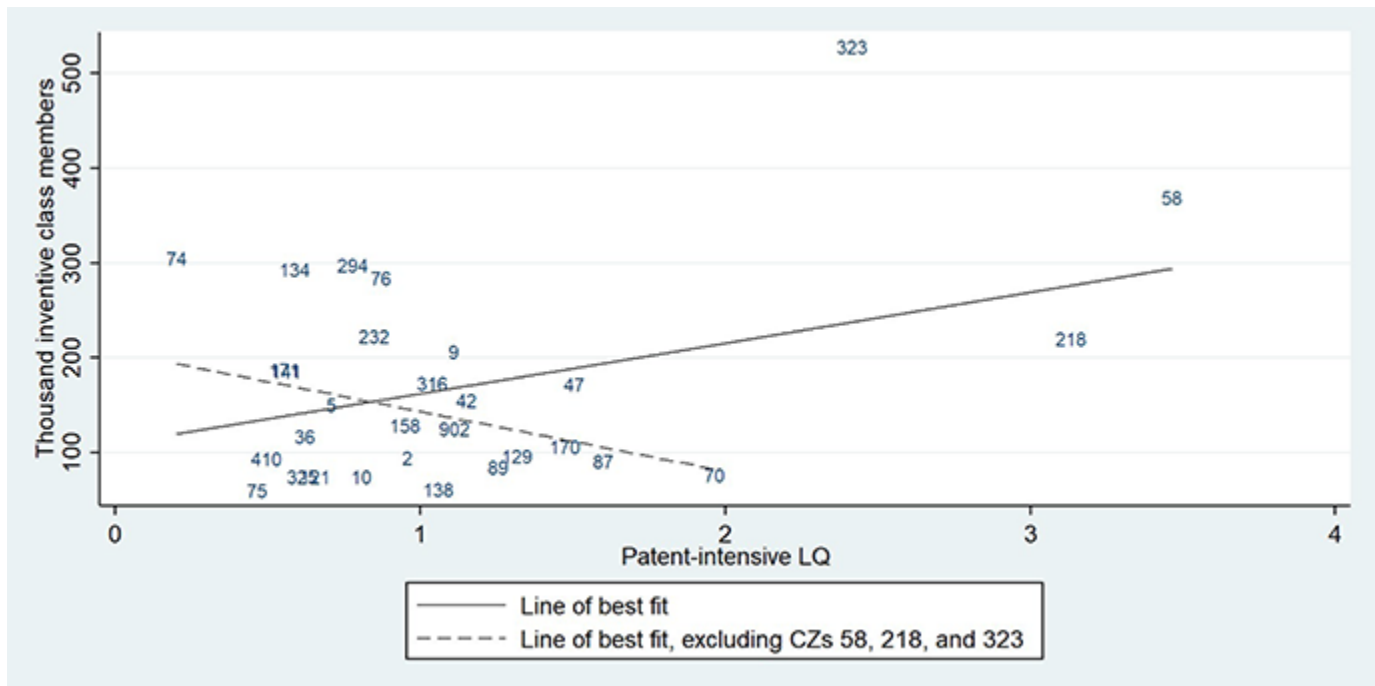
The Economic Research Service (ERS) 2000 commuting zone (CZ) IDs identified in figure (available at: <https://ers.usda.gov/data-products/commuting-zones-and-labor-market-areas>). The 2000 ERS CZs are constructed using intercounty commuter flow data from the 2000 Census of Population. No naming protocol for commuting zones was developed, so the Commuting zone description names a statistical area contained in the CZ. Information on the constituent counties making up each Commuting zone ID is available at the website along with documentation of how the CZs were constructed. The group of patent-intensive industries is characterized by the above-average utility patent intensities (i.e., patent-to-employee ratios) of its industries. Select three- and four-digit industries within the following North American Industry Classification System subsectors are included: computer and electronic product manufacturing; chemical manufacturing; electrical equipment, appliance, and component manufacturing; machinery manufacturing; and miscellaneous manufacturing (Department of Commerce 2012). A location quotient of more than 1.000 indicates a CZ has a higher share of patent-intensive industry employment than the nation as a whole.

Source(s):

Census Bureau, 2000 Census Special Tabulation; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998; Department of Commerce, 2012, *Intellectual Property and the U.S. Economy: Industries in Focus*, available at https://www.uspto.gov/sites/default/files/news/publications/IP_Report_March_2012.pdf.

FIGURE 3

Inventive class membership, by patent-intensive location quotient—urban commuting zones containing a global city: 2000

**Note(s):**

The Economic Research Service (ERS) 2000 commuting zone (CZ) IDs are identified in the figure (available at <https://ers.usda.gov/data-products/commuting-zones-and-labor-market-areas>). Included CZs contain cities that received "alpha," "beta," "gamma," or "high sufficiency" ratings from the Globalization and World Cities Research Network at Loughborough University in 2000 (Beaverstock, Smith, and Taylor 1999). Commuting zones 58, 218, and 323 contain the cities of Chicago, San Jose, and Los Angeles, respectively. The 2000 ERS CZs are constructed using intercounty commuter flow data from the 2000 Census of Population. No naming protocol for CZs was developed, so the Commuter zone description names a statistical area contained in the CZ. Information on the constituent counties making up each Commuting zone ID is available at the website. The group of patent-intensive industries is characterized by the above-average utility patent intensities (i.e., patent-to-employee ratios) of its industries. Select three- and four-digit industries within the following North American Industry Classification System subsectors are included: computer and electronic product manufacturing; chemical manufacturing; electrical equipment, appliance, and component manufacturing; machinery manufacturing; and miscellaneous manufacturing (Department of Commerce 2012). A location quotient of more than 1.000 indicates a CZ has a higher share of patent-intensive industry employment than the nation as a whole.

Source(s):

Census Bureau, 2000 Census Special Tabulation; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998; Beaverstock JV, Smith RG, Taylor PJ, 1999, A Roster of World Cities, *Cities* 16(6):445–58; Department of Commerce, 2012, *Intellectual Property and the U.S. Economy: Industries in Focus*, available at https://www.uspto.gov/sites/default/files/news/publications/IP_Report_March_2012.pdf.

The weak positive correlation between LQ_{PatInd} and IC observed for the UWGC sample and the negative correlation observed for the UCGC sample when Chicago, San Jose, and Los Angeles are excluded could reflect a greater propensity of workers in urban commuting zones to patent in industries not traditionally thought of as patentable (i.e., industries outside of manufacturing) compared to those in rural commuting zones. The results of the iterative regression analysis in section 3 for urban commuting zones suggest an urban manufacturing industry that is concentrated in production of high-technology goods ("electrical, electronics, and electromechanical assemblers" is the only production occupation with a consistent association with invention based on the urban analysis) and an inventive economy that includes a more diverse mix of industries. In years following our study period, the largest subcategory of patents for metropolitan statistical areas (MSAs) have included the usual suspects of computer hardware and peripherals (San Jose, Austin, Portland, Raleigh), biotechnology (San Francisco, Boston, and Philadelphia), and transportation (Detroit). However, less expectedly, the largest percentage of patents granted during the period 2007–11 in the MSAs containing New York, San Diego, Dallas, Atlanta, and Washington, DC (as well as Los Angeles and Chicago), were to inventors in the communications industry, which has experienced substantial growth in inventive output since the 1980s.

It appears that universities also play a significant role in shaping the diverse landscape of invention in urban commuting zones. Rothwell et al. (2013) connect patenting productivity in urban regions to the co-location of research universities—and, more specifically, to the availability of graduate programs in science disciplines. They determine that residents of the 48 MSAs with highly ranked doctoral programs in the sciences were responsible for 62% of all patents produced between 2007 and 2011, despite containing only 46% of the total metropolitan population. While research universities are likely to be a driving force for innovation in large urban commuting zones, such as Harvard University in Boston and University of Pennsylvania in Philadelphia, in urban regions with smaller populations, large research universities are also likely to dominate the local labor market, diluting regional concentration in patent-intensive industries. A stronger relationship between universities and the inventive economy in UWGC commuting zones seems plausible based on the data. Correlation coefficients for student density (students per square mile) and the variables *IC* and *Patents* in UWGC commuting zones are 0.65 and 0.52, respectively, compared to 0.42 and 0.32 for rural commuting zones and 0.33 and 0.04 for urban commuting zones containing a global city. Top urban commuting zones without a global city when ranked by inventive class include the commuting zones containing Yale University and the University of Michigan,²⁸ which are associated with relatively low patent-intensive location quotients of 0.70 and 0.51, respectively. However, notable exceptions exist. For example, the commuting zone containing Rochester, NY ($LQPatInd = 2.11$), has a large manufacturing presence despite being home to several research universities.

Another factor that must be considered is the spatial division of inventive labor and production workers by multi-unit firms in rural and urban regions.²⁹ Tecu observes that “firms...face a trade-off between locating R&D in research hubs to take advantage of external knowledge spillovers and locating R&D close to production to improve internal communication” (2013:2). The traditional notion of patent-intensive manufacturing industries which invent and produce in the same locations appears strongest for rural commuting zones based on the larger positive correlation between rural *LQPatInd* and *IC*. A notable exception to this is the urban commuting zone containing San Jose, the most inventive commuting zone by any metric, which has a large manufacturing base as well as a large inventive population. In her empirical analysis of the relationship between inventive output and the co-location of production and R&D in the chemicals and allied products industry, Tecu (2013) finds that a 10% increase in the size of a firm’s production workforce in a given MSA is associated with a 10% increase in the number of patents produced by the firm in the same MSA. If Tecu’s analysis could be narrowed to the rural case, it would provide additional insights into the co-location of production and R&D workers in rural commuting zones.

Robustness Checks and Limitations of the Analysis

To test the robustness of the results presented in the preceding section, several variations of the baseline simultaneous equations model are implemented for the rural and urban samples. In vector **Geo** of equation 2 and equation 3, categorical variables capturing geographic region and degree of urbanization/population of each commuting zone are included in the baseline specification to control for unobserved regional characteristics that may contribute to patent production and size of the considered population subsets. A likely byproduct of this choice is the dilution of results for the regressors with a variability closely linked to these spatial factors. To evaluate how the inclusion of Census region and RUCC controls impacts our results, the baseline model is first recalculated with these variables omitted. The associated results for rural and urban commuting zones are presented in [appendix table A-1](#) and [appendix table A-2](#) in the appendix.

As expected, deviations from the baseline results are visible in [appendix table A-1](#) and [appendix table A-2](#). Notably, significant coefficients on natural amenity rank—positive in the patents regression and negative in the population subset regression—are now observable for additional specifications in the rural and urban analyses.³⁰ Collectively, these results may be indicative of an indirect process in which natural amenities support invention by positively impacting patenting productivity, which in turn contributes to the agglomeration of knowledge workers. In the rural case, the patents equation results may be picking up the higher patenting propensity of commuting zones in the West Census region compared to those in the Northeast Census region, *ceteris paribus*;³¹ commuting zones in the West Census region have the highest natural amenity ranks on average. Negative coefficients on *ProxUrbCen* in the rural population subset equations are more precisely estimated when geographic controls are excluded (though still insignificant). Positive impacts of unemployment rate and crime rate are also now visible in results for the rural SET regression; each of these variables is positively associated with degree of urbanization in the rural sample.

In results for the rural patents equations in [appendix table A-1](#), coefficients on *WageRentR* are larger in magnitude compared to the baseline case, and the pattern of significance across specifications has been reversed; estimated effects from the *IC* and *SET* regressions are now significant (at the 5% level), while those from the *CC* and *BA* regressions are no longer significant. Changes in significance of point estimates are also visible for *PatStock*, *UniResExp*, and *LQPatInd* in the patents equation for inventive class and *LQPatInd* in the patents equation for educated workforce. As shown in [appendix table A-2](#), following the omission of geographic controls, positive impacts of *UniResExp* on patent production are estimated for the urban *IC*, *SET*, and *CC* specifications.

For rural commuting zones, point estimates for the primary variables interest—the population subsets and patents—are larger in magnitude when the geographic controls are omitted. However, impacts of the individual population subsets on patenting are less precisely estimated in these results; *p*-values for *CC* and *BA* suggest that creative class and educated workforce size, respectively, are not robust predictors of patent production in rural commuting zones. The associated coefficients for *IC* and *SET* remain significant at the 1% and 5% levels, respectively, providing further validation of an important role for these workers in the rural patenting process. In contrast, urban results in [appendix table A-2](#) reveal smaller estimated impacts of the considered population subsets on patent production, with the coefficients on *IC* and *BA* no longer significantly estimated.

It is admittedly difficult to make an ironclad case for causality based on the cross-sectional models used in this study. Unfortunately, this is an unavoidable limitation, as detailed occupation data were issued for one calendar year only. Excluding natural amenity rank, location quotient, and historic patent stock, the remaining independent variables included in the simultaneous equations models are defined using data from the year 2000. Year 2000 data are used to define these variables to maximize the number of commuting zones represented in the analysis; prior to the implementation of the American Community Survey in 2005, usable county-level data are scarcer for intervening decennial Census years. However, an obvious drawback to this approach is that it opens the door for reverse causality between the independent

year 2000 measures and the dependent occupational employment measures. Therefore, in a second and third set of robustness checks, the independent variables from the 3SLS analysis defined using year 2000 data are substituted with corresponding lags from 1998 and 1990, respectively.³² The associated results are presented in [appendix table A-3](#), [appendix table A-4](#), [appendix table A-5](#), and [appendix table A-6](#).

Results for the rural sample employing 1998 and 1990 lags³³—including those for *IC*, *SET*, *CC*, and *BA* in patents equations and *Patents* in population subset equations—are generally consistent with the baseline rural results, with slight deviations in magnitude and significance of estimated effects. A notable exception is the estimated effect of 1990 university research expenditures, which now shows a positive association with patent production for *all* population subset specifications, with an average point estimate of 1.2. This likely highlights the protracted nature of the inventive process, where breakthroughs can occur years after a project is launched. The 1990 crime rate additionally demonstrates a negative association with *IC*, *SET*, and *CC* population sizes in rural regions that is not visible in the baseline results. However, it is notable that this measure displays a high degree of variability over time. Between 1990 and 2000, 72% percent of rural commuting zones saw decreased crime rates, with observed percentage changes ranging from -89% to 919%.

The urban lagged results, provided in [appendix table A-4](#) and [appendix table A-6](#) in the appendix, cast further doubt on the robustness of estimated impacts of the population subsets on patent production in the baseline urban analysis. When the urban model is re-estimated with 1998 and 1990 lags, the coefficients on *SET*, *IC*, and *BA* become insignificant compared to the baseline case. As is the case for the rural sample, a strong positive association is observed between 1990 *UniResExp* and patent production, with point estimates ranging from 13.0 to 14.2. However, positive relationships are observed between the 1990 crime rate and the considered population subsets, in contrast the negative relationships observed in rural *IC*, *SET*, and *CC* specifications. Remaining differences between the lagged and baseline results for rural and urban commuting zones may be attributable to differences in sample composition across specifications.³⁴

Although mean variance inflation factors (VIFs) for the structural equations in the baseline rural and urban analyses do not exceed 3.7—well below Gujarati’s “rule of thumb” threshold of 10 for high collinearity (2003:362)—it is notable that strong pairwise correlations exist between the considered populations of knowledge workers and *UniResExp* and *PatStock*, respectively, in the urban sample (as seen in [table 8](#)). Although both variables have strong a priori associations with patenting, the multicollinearity introduced into the model by their inclusion could result in a loss of statistical power for the populations of interest in equation 2. However, when both *PatStock* and *UniResExp* are excluded in the structural equation for patents in the urban baseline model (results available upon request), each of the population subsets is associated with an insignificant effect in the corresponding regression, suggesting that this result—also visible in the above-mentioned robustness checks—is not an artifact of multicollinearity.

In contrast to the strong positive correlations observed for the individual populations of knowledge workers and university research expenditures and patent stock, respectively, in the urban sample, the corresponding rural correlation coefficients are surprisingly low, ranging from 0.33 to 0.41 across the considered groups of knowledge workers for *UniResExp* and from 0.30 to 0.38 for *PatStock*. This further points to major differences between the inventive economies of rural and urban regions and cautions that what is gained in simplicity by adopting identical models of rural and urban invention can be lost to model misspecification in one case.

The empirical strategy also cannot account for characteristics of workers within each considered subpopulation of knowledge workers and how these unobserved characteristics may impact regional innovation systems. For example, it may be the case that inventive regions inherently attract the workers from each subpopulation with the greatest inventive potential.

Conclusions

The aim of this paper is to refine and assess an occupation-specific human capital approach to the regional analysis of patenting first suggested by Wojan, Dotzel, and Low (2015). Drawing conclusions about the inventive capacity of regions based on patents per capita fails to consider regional differences in the distribution of workers who might plausibly contribute to patenting and the much larger nonpatenting and dependent populations of children and the elderly.

We introduce several modifications to Wojan et al.'s (2015) original analysis, including use of a special tabulation of more-detailed occupation data and added controls for regional characteristics that might confound the selection of patenting occupations. In another departure from Wojan et al. (2015), we limit the universe of candidate occupations for the inventive class to those whose workers engage in the development, design, or creation of novel ideas at a sufficient level. We then critically evaluate the updated construct by implementing a simultaneous equations model of the interrelationship between inventive class composition and productivity in terms of patent production. Alternative subpopulations of knowledge workers (i.e., denominators) are substituted for the inventive class in this portion of the analysis to assess the value-added of the updated metric. The modifications made to the Wojan et al.'s (2015) analysis are effective in removing spurious occupations represented in the original inventive class that lack a discernible connection to patenting, including customer service representatives and entertainers and performers.

Results of the standardization and decomposition analysis suggest that the newly defined inventive class, though smaller, is more productive than the inventive class defined by Wojan et al. (2015). While observed patents per capita rates indicate that global cities are approximately six times more productive than rural areas in producing patents, when inventive class population share is held constant across the two populations, global cities are only twice as productive. In a departure from Wojan et al.'s finding, this result suggests that differences in compositional factors across regions are the main driver of differences in observed population-denominated patenting rates across rural and urban areas.

Going forward, the decomposition of population-based regional patenting rates into a rate factor and a compositional factor raises empirical questions regarding the salience of explaining differences in patenting productivity based on individual variables. For example, if variables such as human capital endowments or the creative class employment share in the local economy are more strongly associated with the compositional factor than the rate factor, then a purported boost to regional inventiveness from either could be more of an artifact of shifting population than an explanation for increased patenting productivity (Qian 2013; Boschma and Fritsch 2009). In a similar fashion, using patents per capita as an independent variable to proxy for innovation may confound the compositional and productivity contributions to constructs such as regional inequality (Lee and Rodríguez-Pose 2013). Future research attempting to identify the true drivers of regional inventiveness, or the implications of regional inventiveness on other phenomena of interest, should recognize the poor construct validity of the patents per capita measure and use a measure denominated by a subpopulation that more plausibly contributes to patenting.

Simultaneous equation results confirm the existence of an interrelationship between patent production and membership in our updated inventive class in rural regions and indicate that the inventive class more effectively picks up the contribution of rural workers in patent-intensive industries compared to three alternative populations of knowledge workers, a significant finding. Although the SET workforce may more effectively predict patent production in urban regions, excluding the additional occupations identified to be associated with invention (specifically, the production occupations) from the patenting rate denominator will serve to bias the estimate of patenting productivity in rural regions. By isolating the occupation-specific human capital most strongly associated with patenting, the analysis also identifies a seeming disarticulation of the inventive class from patent-intensive manufacturing employees in urban areas and the continued integration of these two classes of workers in rural regions.

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Notes

- 1 As first conceptualized by Schumpeter (1939) and later explained by Carlino and Kerr, “invention is the creation of a new product, service, or process, whereas innovation is the commercialization or introduction of that product or service into the market” (2014:4).
- 2 The SET occupations are a nonstandard taxonomy comprised of Science occupations, Engineering occupations, Science and Engineering (S&E) technicians/technologists, and Other S&E-related occupations (see [appendix table A-1 : https://www.nsf.gov/statistics/2020/nsf20300/#technical&chp3](https://www.nsf.gov/statistics/2020/nsf20300/#technical&chp3)). Postsecondary teachers in S&E are not included within SET. S&E managers are also not included in SET. See Dotzel (2017:148–9) for a list of the 48 occupations.
- 3 Each commuting zone is categorized as “rural” or “urban” based on the Rural-Urban Continuum Code (RUCC) of the most urban county in the commuting zone. Urban commuting zones are defined as those containing at least one county associated with RUCC 1, 2, or 3 (the most “urban” RUCCs). All remaining commuting zones are categorized as rural.
- 4 This choice is made to maintain consistency with Wojan et al., who include a total of 20 occupation shares in each regression “to mitigate the effects of collinearity between occupation shares” (2015:540). Mean variance inflation factors for the 19 non-SET occupation shares and *SETSh* in the rural and urban analyses are 1.4 and 2.2, respectively.
- 5 Since RUCCs range from 1 to 9, with 1 being the most urban designation and 9 being the most rural designation, in practice this means that the lowest RUCC corresponding to a county in the commuting zone is assigned to the commuting zone.
- 6 The addition of commuting zone population as a regressor in equation 1 results in loss of statistical power for these controls in addition to population density, suggesting that PopDens and the RUCC and Census region dummy variables sufficiently control for differences in population size across regions.
- 7 Utility patents “apply to processes, machines, articles of manufacture, composition of matter, or any new and useful improvements thereof” (Department of Commerce 2012:5).
- 8 Team-created patents are equally (and fractionally) apportioned to team members.
- 9 The “Importance” rating “indicates the degree of importance a particular descriptor is to the occupation” and ranges from “‘Not Important’ (1) to ‘Extremely Important’ (5).” The “Level” rating ranges from 0 to 7 and “indicates the degree...to which a particular descriptor is required or needed to perform the occupation” (O*NET OnLine 2017a).
- 10 TC Importance and Level ratings all considered SET and not-SET occupations and summary statistics for associated occupation shares are available upon request.
- 11 Among the 114 Census occupations omitted from the analysis for not meeting these criteria are “bus drivers” and “janitors and building cleaners.”
- 12 Following Wojan et al. (2015), we additionally intended to include occupations associated with positive and significant coefficients in at least 50% of their regressions in the metro and nonmetro analysis in our inventive subset to account for inventive processes that appear to be widespread, if not clearly defined. However, no occupations met these criteria.
- 13 “Customer service representatives” was not a candidate occupation in the analysis since associated TC Importance and Level ratings (1.1 and 0.3, respectively) are less than the minimum ratings across SET occupations.
- 14 These detailed occupations are not suboccupations of the summary occupations identified as inventive in the 2015 study.

- 15** These commuting zones include cities that received an “alpha,” “beta,” “gamma,” or “high sufficiency” rating from the Globalization and World Cities (GaWC) Research Network at Loughborough University (Beaverstock, Smith, and Taylor 1999).
- 16** See Li (2017) for examples of the user-written Stata command “rdecompose” for decomposing aggregate or cross-listed data.
- 17** Wojan et al. (2015) sort commuting zones containing global cities into two populations based on whether their 1975–2000 population growth rate falls above or below the global city median growth rate. The allocation method is essentially the same.
- 18** The high-growth global city population is characterized by a rate factor of 0.0793 and a compositional factor of 0.0426, compared to factors of 0.0506 and 0.0668, respectively, in Wojan et al.’s (2015) analysis, while the low-growth global city population has a rate factor of 0.0569 and a compositional factor of 0.0456, compared to factors of 0.0360 and 0.0720, respectively, in the previous study.
- 19** This value is generally equal to $\alpha\text{-effect} / (\alpha\text{-effect} + \beta\text{-effect}) \times 100$. In this case, α represents patents produced per inventive class member and β represents share of total population in the inventive class. Since the β -effect (–0.0002) is less than 0, the α -effect (0.0010) exceeds the sum of the α and β -effects, resulting in an estimated impact greater than 100%.
- 20** “Rural” commuting zones are those containing no metro counties (i.e., all counties are assigned Rural-Urban Continuum codes 4–9) in 2003. These are referred to as ‘predominately rural’ commuting zones in Wojan et al.’s (2015) study. The ‘urban, without a global city’ category is comprised of the metropolitan commuting zones (RUCCs 1–3) not containing a global city.
- 21** For example, Das Gupta’s (2003) two-factor, three-population methodology ensures that the sum of the UCGC-UWGC and UWGC-Rural effects equals the UCGC-Rural effect for both factors.
- 22** Unlike Faggian and McCann (2009), we do not include a measure of small business presence as a predictor of patent production, as the authors find no evidence that small firms alone are important for regional invention. Furthermore, when the percentage of firms with less than 20 employees is included as a regressor in our structural equation for patents (i.e., equation 2), estimated effects are not statistically significant.
- 23** The group of patent-intensive industries is characterized by the above-average utility patent intensities (i.e., patent-to-employee ratios) of its industries. Select three- and four-digit industries within the following North American Industry Classification System subsectors are included: computer and electronic product manufacturing; chemical manufacturing; electrical equipment, appliance, and component manufacturing; machinery manufacturing; and miscellaneous manufacturing (Department of Commerce 2012).
- 24** Following McCann and Faggian (2009), the R&D variable is only included in the patenting equations and not in the population subset or human capital equations. While this specification may be most appropriate for the more general university graduate or creative class human capital variables, an argument can be made for including it in the inventive class and SET equations. For this comparative analysis, we only include the R&D variable in the patenting equation. Future research using the inventive class or SET occupations should consider the relevance of R&D measures as potential attractors.
- 25** As acknowledged in section 2, patents are not representative of all types of innovation and not all sectors use patents to protect intellectual property (e.g., knowledge-intensive service sectors) (Tomlinson and Miles 1999). Accordingly, not all workers who have a hand in innovation contribute to patentable invention. We limit our analysis to those knowledge workers with a plausible direct connection to invention.

- 26** Between 2000 and 2003, 94% of inventors named on U.S. triadic patents had at least a bachelor's degree, while 45% had a PhD (Walsh and Nagaoka 2009).
- 27** Magnitudes of Pearson correlation coefficients between the alternative patenting rates and patents per capita vary as expected, given the respective subpopulation means for rural and urban commuting zones displayed in [table 7](#) . In both rural and urban samples, the patenting rate of the smallest subpopulation on average (SET workforce) displays the weakest correlation with patents per capita, while the patenting rate of the largest subpopulation on average (educated workforce) displays the strongest correlation. These correlation coefficients are available on request.
- 28** When urban commuting zones without a global city are ranked by *IC*, each of these commuting zones falls within the top 10 for a given metropolitan RUCC category.
- 29** Of the multiunit firms from the NSF Survey of Industrial R&D engaged in the inventive economy during the decade preceding 1996, 70% of firms patented in more than one MSA and, on average, firms patented in five MSAs (Tecu 2013).
- 30** This pattern of effects for *NatAmen* is also observable for the urban baseline *SET* and *IC* regressions.
- 31** Coefficients on the categorical indicator for the West Census region (in reference to the Northeast Census region) in the rural baseline patents equation results are positive in each case. These results, excluded from [table 9](#) , are available on request.
- 32** These variables are population density, university research expenditures, unemployment rate, crime rate, proximity to urban center, and wage-rental ratio.
- 33** Results for the rural commuting zones based on the 1998 and 1990 lags are provided in [appendix table A-3](#) and [appendix table A-5](#) , respectively.
- 34** Due to differences in data availability by year, rural results employing lags from 1998 and 1990 are based on 329 and 370 observations, respectively, compared to 358 observations in the baseline case. Baseline urban results are calculated from 301 observations compared to 295 and 307 observations, respectively, when 1998 and 1990 lags are substituted.

Appendix

Table	Title
A-1	Results for simultaneous equations model excluding regional controls—rural commuting zones
A-2	Results for simultaneous equations model excluding regional controls—urban commuting zones
A-3	Results for simultaneous equations model with 1998 lags—rural commuting zones
A-4	Results for simultaneous equations model with 1998 lags—urban commuting zones
A-5	Results for simultaneous equations model with 1990 lags—rural commuting zones
A-6	Results for simultaneous equations model with 1990 lags—urban commuting zones

TABLE A-1

Results for simultaneous equations model excluding regional controls—rural commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)			Science, engineering, and technical (SET) employment			Creative class (CC)			At least 4-year college degree (BA)		
	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value
Patents dependent variable												
IC	0.115	***	0.009	-	-		-	-	-	-	-	-
SET	-	-	-	0.290	**	0.036	-	-	-	-	-	-
CC	-	-	-	-	-	-	0.034	-	0.347	-	-	-
BA	-	-	-	-	-	-	-	-	-	0.020	-	0.315
1975–80 patent stock (PatStock)	-0.183		0.215	-0.455		0.118	-0.176		0.580	-0.121		0.632
Population density (PopDens)	-0.711		0.312	-1.415		0.229	-0.358		0.858	-0.263		0.863
Wage-rental ratio (WageRentR)	32.690	**	0.016	56.380	**	0.044	46.289		0.321	37.906		0.312
Natural amenity rank (NatAmen)	12.576	**	0.036	12.540		0.113	11.639		0.349	7.098		0.389
University research expenditures (UniResExp)	-1.114		0.221	-3.311		0.158	-1.069		0.681	-0.759		0.741
Location quotient for patent-intensive industries (LQPatInd)	-25.049	*	0.053	-21.815		0.159	-7.069		0.598	5.664		0.395
Root mean square error (RMSE)	77.018			126.017			90.135			78.043		
Chi-squared	334.368			129.495			182.434			231.835		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	1.502			1.503			1.461			1.443		
Population subset equation												
Patents	16.081	***	<1.00E-08	10.944	***	<1.00E-08	51.457	***	<1.00E-08	76.473	***	<1.00E-08
Unemployment rate (UR)	18.444		0.156	19.478	**	0.034	56.134		(0.402)	69.059		0.482
WageRentR	-207.397	***	0.000	-108.358	***	0.002	-1,062.4	***	1.60E-07	-1,550.84	***	1.50E-07
NatAmen	-104.238	**	0.013	-33.729		0.208	-308.854	*	0.058	-314.597		0.195
Crime	2.655		0.232	2.293	*	0.086	8.958		0.107	10.478		0.199
Proximity to urban center (ProxUrbCen)	-0.309		0.127	-0.288		0.129	-1.306		0.125	-1.346		0.237
LQPatInd	148.822	**	0.012	-7.211		0.851	-76.130		0.744	-613.964	*	0.077
RMSE	679.917			432.517			2644.331			3949.441		
Chi-squared	334.368			129.495			182.434			231.835		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	1.482			1.482			1.482			1.482		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.**Note(s):**

Structural equation estimates are based on 358 observations.

Source(s):

Authors' estimation using U.S. Patent and Trademark Office; Census Bureau, Special Tabulation (2000), 2000 Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Data System, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

TABLE A-2

Results for simultaneous equations model excluding regional controls—urban commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)			Science, engineering, and technical (SET) employment			Creative class (CC)			At least 4-year college degree (BA)		
	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value
Patents dependent variable												
IC	0.036	-	0.107	-	-	-	-	-	-	-	-	-
SET	-	-	-	0.048	*	0.091	-	-	-	-	-	-
CC	-	-	-	-	-	-	0.009	-	0.310	-	-	-
BA	-	-	-	-	-	-	-	-	-	0.008	-	0.256
1975–80 patent stock (PatStock)	0.652		0.153	0.669	*	0.087	0.816		0.128	0.611		0.320
Population density (PopDens)	-0.110		0.638	-0.135		0.507	0.044		0.944	-0.097		0.923
Wage-rental ratio (WageRentR)	-97.622		0.783	-72.204		0.838	-49.050		0.898	-10.511		0.978
Natural amenity rank (NatAmen)	844.033	***	<0.001	860.586	***	<0.001	896.446	***	<0.001	868.456	***	<0.001
University research expenditures (UniResExp)	4.231	*	0.090	4.790	*	0.059	5.361	**	0.029	4.616		0.114
Location quotient for patent-intensive industries (LQPatInd)	1,303.392	***	<0.001	1,377.616	***	<0.001	1,415.633	***	<0.001	1,492.213	***	<0.001
Root mean square error (RMSE)	2,551.155			2,522.494			2,772.561			2,827.890		
Chi-squared	1,018.295			1,005.776			906.521			932.065		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.377			3.059			3.343			3.710		
Population subset equation												
Patents	14.505	***	<0.001	10.076	***	<0.001	45.228	***	<0.001	63.518	***	<0.001
Unemployment rate (UR)	-1,340.357		0.284	-1,202.309		0.171	-4,121.518		0.354	-3,519.910		0.591
WageRentR	1497.594		0.784	664.515		0.860	253.342		0.990	-2,317.912		0.937
NatAmen	-9,701.234	***	<0.001	-6,767.009	***	<0.001	-30,302.539	***	0.002	-45,703.148	***	0.001
Crime	142.448		0.194	105.163		0.143	572.835		0.247	473.930		0.503
Proximity to urban center (ProxUrbCen)	-30.093		0.176	-24.103		0.121	-107.654		0.208	-123.718		0.300
LQPatInd	-19,031.969	***	<0.001	-14,707.899	***	<0.001	-68,930.02	***	<0.001	-103,473.93	***	<0.001
RMSE	37,414.982			25,825.715			139,000.000			199,000.000		
Chi-squared	721.383			731.342			505.796			480.232		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	1.424			1.424			1.424			1.424		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.**Note(s):**

Structural equation estimates are based on 358 observations.

Source(s):

Authors' estimation using U.S. Patent and Trademark Office; Census Bureau, Special Tabulation (2000), 2000 Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Data System, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

TABLE A-3

Results for simultaneous equations model with 1998 lags—rural commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)		Science, engineering, and technical (SET) employment		Creative class (CC)		At least 4-year college degree (BA)					
	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value	Coefficient estimate	p-value				
Patents dependent variable												
IC	0.053	***	5.22E-05	-	-	-	-	-	-	-	-	-
SET	-	-	-	0.102	***	2.66E-04	-	-	-	-	-	-
CC	-	-	-	-	-	-	0.022	***	0.003	-	-	-
BA	-	-	-	-	-	-	-	-	-	0.017	***	0.009
1975–80 patent stock (PatStock)	0.077	**	0.037	0.021		0.670	0.047		0.345	0.015		0.806
Population density (PopDens)	0.028		0.877	-0.024		0.905	-0.079		0.815	-0.080		0.831
Wage-rental ratio (WageRentR)	2.231		0.380	2.729		0.338	3.025		0.384	2.260		0.571
Natural amenity rank (NatAmen)	2.041		0.459	1.287		0.673	-3.280		0.414	-6.944		0.193
University research expenditures (UniResExp)	0.619	**	0.042	0.113		0.829	0.294		0.589	0.025		0.974
Location quotient for patent-intensive industries (LQPatInd)	-4.380		0.376	-0.026		0.996	4.006		0.380	11.275	**	0.017
Root mean square error (RMSE)	35.140			39.431			50.411			57.763		
Chi-squared	665.812			673.690			495.559			502.329		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.391			3.402			3.362			3.383		
Population subset equation												
Patents	12.621	***	<1.00E-08	9.068	***	<1.00E-08	38.334	***	<1.00E-08	57.478	***	<1.00E-08
Unemployment rate (UR)	-9.702		0.316	-1.970		0.626	-19.472		0.531	-5.228		0.923
WageRentR	-74.166		0.125	-32.340		0.282	-202.734		0.273	-164.034		0.553
NatAmen	-35.807		0.488	-11.760		0.715	161.523		0.414	417.482		0.152
Crime	-2.556		0.367	-0.191		0.915	-2.052		0.844	0.313		0.983
Proximity to urban center (ProxUrbCen)	-0.355		0.170	-0.040		0.710	-0.458		0.592	-0.172		0.871
LQPatInd	173.306	***	0.003	12.274		0.740	-43.419		0.849	-610.417	*	0.069
RMSE	604.616			379.259			2,327.936			3,436.582		
Chi-squared	839.564			810.320			662.437			626.077		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	3.164			3.164			3.164			3.164		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.**Note(s):**

PopDens, WageRentR, UniResExp, UR, Crime, and ProxUrbCen are lagged to 1998. Structural equation estimates are based on 329 observations. Controls for Census region and Rural-Urban Continuum Code are included in each regression.

Source(s):

Authors' estimation using U.S. Patent and Trademark Office; Census Bureau, Special Tabulation (2000), 2000 Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Data System, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

TABLE A-4

Results for simultaneous equations model with 1998 lags—urban commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)			Science, engineering, and technical (SET) employment			Creative class (CC)			At least 4-year college degree (BA)		
	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value
Patents dependent variable												
IC	0.021	-	0.660	-	-	-	-	-	-	-	-	-
SET	-	-	-	0.033	-	0.605	-	-	-	-	-	-
CC	-	-	-	-	-	-	0.001	-	0.964	-	-	-
BA	-	-	-	-	-	-	-	-	-	0.002	-	0.892
1975–80 patent stock (PatStock)	0.887		0.335	0.804		0.313	1.208		0.249	1.045		0.407
Population density (PopDens)	-0.294		0.252	-0.388	*	0.095	0.164		0.875	0.327		0.861
Wage-rental ratio (WageRentR)	32.485		0.906	31.501		0.908	54.764		0.847	48.977		0.868
Natural amenity rank (NatAmen)	711.664	**	0.013	744.450	***	0.004	769.971	**	0.033	740.143	*	0.077
University research expenditures (UniResExp)	8.550		0.246	8.931		0.250	11.316		0.112	10.485		0.232
Location quotient for patent-intensive industries (LQPatInd)	1,319.772	***	5.90E-07	1,377.934	***	2.50E-07	1,357.145	***	8.54E-06	1,408.509	***	8.61E-05
Root mean square error (RMSE)	2,573.390			2,531.145			2,725.097			2,756.754		
Chi-squared	960.228			959.819			911.429			941.924		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.675			3.442			3.613			3.784		
Population subset equation												
Patents	14.324	***	<1.00E-08	10.012	***	<1.00E-08	44.681	***	<1.00E-08	62.592	***	<1.00E-08
Unemployment rate (UR)	-247.231		0.753	-263.662		0.636	-597.505		0.836	-184.117		0.965
WageRentR	623.807		0.877	405.687		0.884	2,204.700		0.883	4,546.623		0.832
NatAmen	-7,772.615	**	0.033	-6,313.327	**	0.013	-18,627.707		0.171	-25,691.080		0.186
Crime	121.722		0.217	74.786		0.244	558.690		0.193	632.919		0.296
Proximity to urban center (ProxUrbCen)	-23.179		0.444	-18.337		0.393	-71.416		0.518	-72.421		0.636
LQPatInd	-18,578.916	***	1.04E-05	-14,410.255	***	8.10E-07	-66,994.938	***	2.13E-05	-1.00E+05	***	7.97E-06
RMSE	36,834.638			25,543.749			1.370E+05			1.950E+05		
Chi-squared	728.605			736.516			511.603			487.382		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	2.275			2.275			2.275			2.275		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Note(s):

PopDens, WageRentR, UniResExp, UR, Crime, and ProxUrbCen are lagged to 1998. Structural equation estimates are based on 295 observations. Controls for Census region and Rural-Urban Continuum Code are included in each regression.

Source(s):

Authors' estimation using U.S. Patent and Trademark Office; Census Bureau, Special Tabulation (2000), 2000 Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Data System, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

TABLE A-5

Results for simultaneous equations model with 1990 lags—rural commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)			Science, engineering, and technical (SET) employment			Creative class (CC)			At least 4-year college degree (BA)		
	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value
Patents dependent variable												
IC	0.032	***	1.07E-03									
SET				0.054	***	9.22E-03						
CC							0.011	***	1.40E-03			
BA										0.009	***	1.38E-03
1975–80 patent stock (PatStock)	0.134	***	4.08E-05	0.115	***	0.001	0.135	***	8.07E-06	0.114	***	0.001
Population density (PopDens)	0.219		0.218	0.230		0.153	0.168		0.421	0.144		0.493
Wage-rental ratio (WageRentR)	1.682		0.580	1.700		0.583	3.431		0.312	4.428		0.229
Natural amenity rank (NatAmen)	2.352		0.347	1.782		0.482	-0.110		0.968	-2.056		0.503
University research expenditures (UniResExp)	1.288	***	0.001	1.167	**	0.013	1.271	***	0.003	1.057	**	0.044
Location quotient for patent-intensive industries (LQPatInd)	2.605		0.496	6.420	**	0.044	8.896	***	0.002	11.997	***	5.04E-05
Root mean square error (RMSE)	30.977			31.405			33.283			35.218		
Chi-squared	687.393			672.053			617.968			571.639		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.487			3.478			3.452			3.470		
Population subset equation												
Patents	13.821	***	<1.00E-08	9.380	***	<1.00E-08	42.166	***	<1.00E-08	60.767	***	<1.00E-08
Unemployment rate (UR)	-6.210		0.588	-5.598		0.385	-45.076		0.298	-76.618		0.208
WageRentR	-188.839	***	0.002	-103.327	***	0.008	-820.848	***	0.001	-1,078.9	***	0.002
NatAmen	-49.557		0.315	-16.068		0.606	56.901		0.764	279.710		0.313
Crime	-6.666	***	0.006	-3.603	**	0.019	-20.033	**	0.031	-20.394		0.124
Proximity to urban center (ProxUrbCen)	-0.512	*	0.086	-0.165		0.307	-1.818	*	0.096	-1.631		0.222
LQPatInd	131.159	**	0.017	-7.672		0.826	-180.183		0.397	-684.519	**	0.028
RMSE	584.026			371.313			2,257.052			3,321.879		
Chi-squared	990.563			908.698			791.282			746.591		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	3.305			3.305			3.305			3.305		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.**Note(s):**

PopDens, WageRentR, UniResExp, UR, Crime, and ProxUrbCen are lagged to 1990. Structural equation estimates are based on 370 observations. Controls for Census region and Rural-Urban Continuum Code are included in each regression.

Source(s):

Authors' estimation using U.S. Patent and Trademark Office; Census Bureau, Special Tabulation (2000), 2000 Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Data System, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

TABLE A-6

Results for simultaneous equations model with 1990 lags—urban commuting zones

(Estimated regression coefficients on patents and population subset)

Variable	Population subset											
	Inventive class (IC)			Science, engineering, and technical (SET) employment			Creative class (CC)			At least 4-year college degree (BA)		
	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value	Coefficient estimate		p-value
Patents dependent variable												
IC	0.016	-	0.474	-	-	-	-	-	-	-	-	-
SET	-	-	-	0.024	-	0.406	-	-	-	-	-	-
CC	-	-	-	-	-	-	0.003	-	0.674	-	-	-
BA	-	-	-	-	-	-	-	-	-	0.003	-	0.672
1975–80 patent stock (PatStock)	1.113	**	0.027	1.076	**	0.013	1.182*	**	0.037	1.110	*	0.075
Population density (PopDens)	-0.197		0.495	-0.317		0.247	0.288		0.660	0.522		0.607
Wage-rental ratio (WageRentR)	-411.929		0.260	-384.873		0.291	-439.507		0.255	-449.847		0.245
Natural amenity rank (NatAmen)	550.612	**	0.017	579.413	**	0.010	543.445	**	0.037	538.322	**	0.045
University research expenditures (UniResExp)	13.045	***	0.005	13.893	***	0.002	14.247	***	0.002	14.239	***	0.004
Location quotient for patent-intensive industries (LQPatInd)	1,191.419	***	1.33E-06	1,223.056	***	8.70E-07	1,253.222	***	4.75E-06	1,295.560	***	7.41E-06
Root mean square error (RMSE)	2,552.841			2,510.494			2,692.624			2,725.356		
Chi-squared	1,078.636			1,058.332			1,004.023			1,023.413		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean variance inflation factor (VIF)	3.374			3.148			3.402			3.517		
Population subset equation												
Patents	13.584	***	<1.00E-08	9.347	***	<1.00E-08	42.664	***	<1.00E-08	59.663	***	<1.00E-08
Unemployment rate (UR)	-759.789		0.295	-704.864		0.179	-2,554.620		0.342	-3,206.771		0.428
WageRentR	7,250.033		0.178	4,560.261		0.216	27,975.158		0.167	41,925.136		0.145
NatAmen	-6,829.17	**	0.042	-5,650.838	**	0.014	-15,510.885		0.219	-20,441.373		0.255
Crime	261.270	**	0.013	193.705	***	0.006	942.270	**	0.019	1,204.408	**	0.032
Proximity to urban center (ProxUrbCen)	-36.770		0.122	-29.114	*	0.086	-95.285		0.267	-115.383		0.350
LQPatInd	-15,330.98	***	1.19E-04	-11,621.99	***	2.04E-05	-57,477.17	***	1.29E-04	-87,142.5	***	4.57E-05
RMSE	34,459.443			23,591.927			1.300E+05			1.850E+05		
Chi-squared	803.360			823.482			559.812			532.736		
p-value	<0.0001			<0.0001			<0.0001			<0.0001		
Mean VIF	2.206			2.206			2.206			2.206		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Note(s):

PopDens, WageRentR, UniResExp, UR, Crime, and ProxUrbCen are lagged to 1990. Structural equation estimates are based on 307 observations. Controls for Census region and Rural-Urban Continuum Code are included in each regression.

Source(s):

Authors' estimation using U.S. Patent and Trademark Office; Census Bureau, Special Tabulation (2000), 2000 Census of Population and Housing, Summary File 1 and Summary File 4, and Shapefile; Integrated Postsecondary Data System, 2000; Department of Agriculture, Economic Research Service, 1999, 2000; Bureau of Labor Statistics, Quarterly Census of Employment and Wages, 1998.

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