

The Evolving U.S. Occupational Structure

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Abstract

Using the text from job ads, we construct a new data set of occupational content from 1960 to 2000. We document that within-occupation task content shifts are at least as important as employment shifts across occupations in accounting for the aggregate decline of routine tasks. Motivated by this pattern, we first bring our new task measures to a reduced-form statistical decomposition. We then embed our measures in an equilibrium model of occupational choice. These two exercises indicate that shifts in the relative demand for tasks account for much of the increase in 90-10 earnings inequality observed over our sample period. **JEL Codes: E24, J20, O33**

1 Introduction

Labor income inequality in the United States has increased considerably over the last several decades. Between 1960 and 2000, the ratio of earnings for the median worker, compared to the worker at the 10th percentile of the earnings distribution, has increased from 2.75 to 2.86. Over the same period, the 90-50 earnings ratio increased even more starkly, from 1.81 to 2.27. Alongside rising inequality, there have been dramatic changes in the composition of U.S. employment. For example, the employment share of occupations intensive in routine tasks has shrunk, while the share of occupations emphasizing nonroutine tasks, as well as social and cognitive skills, has grown (Autor, Levy, and Murnane, 2003; Autor, Katz, and Kearney, 2005; Autor and Dorn, 2013; and Deming, 2017).

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The evidence thus far points to the decline of employment in U.S. occupations intensive in routine tasks, but is largely silent on whether the content of occupations themselves has changed. Meanwhile, case studies of individual occupations have found considerable changes. For example, a report by the [National Research Council \(1999\)](#) suggests that managerial occupations over the second half of the twentieth century increasingly have emphasized team management, coaching skills and tasks, and interaction with customers. The rise in these skills and tasks was accompanied by a decline of managerial tasks related to direct control of subordinates.¹ These findings raise the question of whether managerial occupations are unique in experiencing changes in tasks, or if comparable changes have occurred elsewhere. Moreover, to the extent that job tasks have shifted, what are the implications for the distribution of earnings?

In this paper we show that, in fact, substantial changes in task composition did occur within occupations since 1960.² We also find that these within-occupation changes in task content account for much of the observed increase in earnings inequality. We start by constructing a new data set using the text content of approximately 4.2 million job ads appearing in three major metropolitan newspapers — the *New York Times*, the *Wall Street Journal*, and the *Boston Globe*. We then map the words contained in job ad text to different classifications of task content. Our main strategy relies on [Spitz-Oener’s \(2006\)](#) classification of words into routine (cognitive and manual) and nonroutine (analytic, interactive, and manual) tasks. To validate our new data set, we demonstrate that the measures that result from our mapping correlate, across occupations, with O*NET’s measures of the importance of different tasks.³

We show that, in our database of newspaper ads, words related to nonroutine tasks have been increasing in frequency, while words related to routine tasks (especially routine manual tasks) have declined in frequency between 1960 and 2000. For instance, we find that the frequency of words related to routine cognitive tasks has declined by more than a third over the sample period, from 1.23 mentions per thousand job ad words to 0.76 mentions per

¹The National Research Council report chronicles the evolution of several other occupations. In Section 4 and Appendix D, we link the changes within managerial, clerical, and assembly occupations documented in the report to the new measures we introduce in this paper.

²[Acemoglu and Autor \(2011\)](#), among others, emphasize that skills and tasks refer to different work concepts: “A *task* is a unit of work activity that produces output (goods and services). In contrast, a skill is a worker’s endowment of capabilities for performing various tasks.” (p. 1045, emphasis in the original) We adopt these definitions of skills and tasks throughout our paper.

³We also perform several checks on the data to provide evidence that neither the selection of ads into newspapers nor the fact that our data originate in metropolitan areas bias our results. First, we show that the distribution of ads across occupations is similar to the distribution of employment according to the decennial census (and our results largely agree with analogous comparisons made with online vacancies, e.g., in [Hershbein and Kahn, 2016](#)). Second, we show that the educational requirements by occupation in our data set correlate reasonably well with those observed in the census (Appendix A). Third, we show that trends in the propensity of unemployed workers to search for jobs through help wanted ads does not vary with the task content of their prior occupation (Appendix B). And, fourth, we show that our main results are not driven by the fact that most of our ads come from a selected number of large metro areas (Appendix D.3 and Appendix E.3).

thousand words. The frequency of routine manual tasks has declined even more starkly. The frequency of words related to nonroutine analytic tasks, on the other hand, has increased from 3.43 to 6.04 mentions per thousand job ad words. Mentions of nonroutine interactive tasks have increased from 4.95 to 7.56 mentions per thousand job ad words. Importantly, we find that a large fraction of the aggregate changes in both nonroutine and routine task related words has occurred within occupations, rather than through changes in the occupations' employment shares. These findings hold whether one defines occupations according to 4-digit SOC codes, 6-digit SOC codes, or job titles; and whether one categorizes tasks as in [Spitz-Oener \(2006\)](#), [Firpo, Fortin, and Lemieux \(2014\)](#), or [Deming and Kahn \(2017\)](#).

Having documented these patterns, we provide two alternative quantifications of the relation between changes in the task content of occupations and the rise of inequality in the U.S. The first one relies on decomposition methods applied to the earnings distribution; the second, on an equilibrium model of worker occupational choices and comparative advantage. In both quantifications, we combine commonly used wage and employment data, by occupation and time, with our new task measures.

In our first quantification, we incorporate our occupational measures into [Fortin, Lemieux, and Firpo \(2011\)](#)'s methodology for decomposing changes in the wage distribution across points in time. Using these methods, we break down changes in the distribution of earnings over time into changes in the attributes of workers and their occupations (the "composition" effect), as well as changes in the implicit prices of those observable characteristics (the "wage structure" effect).

Our results suggest that, relative to the upper tail of the income distribution, the content of tasks that were valued highly in low-wage jobs (in particular manual tasks) declined. These task changes, however, come more from changes within the occupations themselves than from shifts of employment across occupations. In the decomposition, changes in occupational task content account, through composition effects, for a 22 log point increase in 90-10 male earnings inequality from 1960 to 2000. (Over this period, the 90-10 ratio for full time male workers increased by 38 log points.) Wage structure effects — changes in tasks' implicit prices — account for a 5 log point decrease in 90-10 inequality. Among the 22 log points that are due to composition effects, routine manual and nonroutine interactive tasks respectively account for a 12 and 9 log point increase in inequality. The contribution of changes in routine cognitive, nonroutine analytic, and nonroutine manual tasks is more modest. If we instead ignore the evolution of occupational characteristics across time, and keep occupations' task measures fixed, composition effects account for a 5 log point increase in 90-10 male inequality. Hence, occupational measures of task intensity account for a large component of the increase in earnings inequality between 1960 and 2000, but only if task measures are allowed to vary across time within occupations.

In our second quantification, which we view as complementary to the [Fortin, Lemieux, and Firpo \(2011\)](#) decomposition, we construct a general equilibrium model of occupational

choice. In our model, individual occupations are represented as a bundle of tasks. Workers' skills govern their abilities to perform each of the individual tasks in their occupation, and give rise to comparative advantage. These skill levels are functions of workers' observable characteristics — like gender, education, and experience — but also contain an idiosyncratic component. Based on their skill levels and the demand for tasks within each occupation, workers select into the occupation with the highest payoff.

We estimate each demographic group's skills to perform different tasks, combining information on demographic groups' earnings and occupation choices. Using our estimated model, we calculate that changes in the relative demands for tasks have led to a 16 log point increase in 90-10 inequality among men, and a 23 log point increase in inequality for men and women combined. The intuition is that workers who are at the bottom of the earnings distribution have a comparative advantage in occupations that are intensive in manual tasks, while the demand for these tasks has declined.

Both the statistical decompositions and our model-based counterfactual exercises have their own advantages, which we expand on below. In spite of their differences, however, both methods indicate that a relative decline in the demand for routine tasks has substantially increased earnings inequality between 1960 and 2000. Moreover, both of these exercises require information on changes in occupations' task content, something that our data set is uniquely suited to measure.

Our paper builds on multiple literatures. The first examines the causes and consequences of the evolution of occupations. [Autor, Levy, and Murnane \(2003\)](#) and [Acemoglu and Autor \(2011\)](#) develop the hypothesis that technological advances have reduced the demand for routine tasks, which, in turn, has led to a reduction in the wages of low- and middle-skill workers. More recently, [Firpo, Fortin, and Lemieux \(2014\)](#) decompose changes in the distribution of wages into the contribution of occupational characteristics and other factors (including de-unionization, changes in minimum wage, and changes in worker demographics). [Deming \(2017\)](#) documents that employment and wage growth has been confined to occupations which are intensive in both social and cognitive skills. [Michaels, Rauch, and Redding \(2016\)](#) extend [Autor, Levy, and Murnane \(2003\)](#) to study changes in employment shares by task content over a longer time horizon. They use a methodology that is related to ours, using the verbs from the Dictionary of Occupational Titles' occupational descriptions and their thesaurus-based meanings. [Burstein, Morales, and Vogel \(2015\)](#) quantify the impact of the adoption of computers on between-group wage inequality. With the exception of [Autor, Levy, and Murnane \(2003\)](#), these papers hold occupational characteristics fixed over time.

Relative to this first literature, our paper contributes with both new measurements and a new quantitative framework of occupations as bundles of tasks. To the measurement of time-varying characteristics of U.S. occupations over the second half of the 20th century, we introduce a new, publicly available data set at the occupation-year level. This data set includes measures of tasks, skill requirements, and other job characteristics between 1940 and

2000.⁴ Because they are built from newspaper text, our data rely on a continuously updated source, and have the advantage over survey-based data of being collected in the field: Firms post these ads while they are actively searching for workers. We view this new data set as complementary to existing data sources currently used to study the evolution of the U.S. labor market.⁵ Outside the U.S. context, one paper that focuses on within-occupation changes is [Spitz-Oener \(2006\)](#), which uses survey data from four waves of German workers to track task changes within and between occupations, from the late 1970s to the late 1990s. A comparable analysis in the U.S. cannot be achieved with existing surveys, and hence one of the contributions of this paper is to undertake the construction and validation of a new data set that allows for an analysis of occupational change in the U.S. Our newly constructed data set not only covers a substantially longer period than the data set used by [Spitz-Oener \(2006\)](#), but also does so continuously throughout our sample and includes a much wider set of task and skill measures.

To study the evolution of individual occupations, we build on [Lagakos and Waugh \(2013\)](#), [Burstein, Morales, and Vogel \(2015\)](#), and [Galle, Rodriguez-Clare, and Yi \(2017\)](#). An innovation is that we model occupations as a bundle of tasks that workers need to perform. We allow for the importance of these tasks to change over time, reflecting what we observe in the data. Because we estimate the skill of workers of different groups to perform these tasks, our model has an observable, time-varying margin of comparative advantage not present in previous models.⁶ The key takeaway from our analysis, resulting from our new measurement and framework, is that the transformation of the U.S. occupational structure, both in the scope of task content changes and the impact of these task changes on inequality, is even more dramatic than previously thought.

Our paper also builds on a recent literature that uses the text from online help wanted ads

⁴Our new data set can be found at http://ssc.wisc.edu/~eatalay/occupation_data. Throughout this paper, we restrict attention to job ads which were published beginning in 1960. We make this restriction since the focus of our paper is on the implications of occupations' task content on increasing labor income inequality, which began in earnest only in the 1960s. This data set has recently been applied by [Anastasopoulos, Borjas, Cook, and Lachanski \(2018\)](#), [Cortes, Jaimovich, and Siu \(2018\)](#), and [Deming and Noray \(2018\)](#).

⁵In particular, it extends what can be accomplished by linking across editions of the Dictionary of Occupational Titles (DOT). For example, [Autor, Levy, and Murnane \(2003\)](#) use the 1977 and 1991 versions of the DOT to compare changes in occupations' task content and computer adoption rates. As [Autor, Levy, and Murnane \(2003\)](#) and [Autor \(2013\)](#) note, the update was not exhaustive across occupations, potentially leading to status quo bias ([Miller, Treiman, Cain, and Roose, 1980](#)). We contrast occupational change measured in our data to what is possible using the DOT in [Appendix D.2](#), and find, as in prior work, that the DOT is limited in its ability to measure time-varying occupational tasks. Using a different approach, [Ross \(2017\)](#) combines the 2003 to 2014 vintages of the O*NET database to construct a panel of occupations' skill and task intensity measures to study changes in routine tasks over this more recent period.

⁶While an exploration of the mechanisms driving task changes is beyond the scope of this paper, we explore one such mechanism in subsequent work ([Atalay, Phongthientham, Sotelo, and Tannenbaum, 2018](#)). There, we extract additional information from vacancy postings: mentions of 48 distinct information and communication technologies. Based on the patterns of task and technology mentions, we argue that technologies tend to increase the demand for worker-performed nonroutine analytic tasks relative to other tasks (though exceptions, like the Microsoft Office Suite, exist).

to study the labor market: how firms and workers match with one another, how firms differ in their job requirements, and how skill requirements have changed since the beginning of the Great Recession.⁷ Using data from CareerBuilder, [Marinescu and Wolthoff \(2016\)](#) document substantial variation in job ads’ skill requirements and stated salaries within narrowly-defined occupation codes. Also using online job ads, [Hershbein and Kahn \(2016\)](#) and [Modestino, Shoag, and Ballance \(2016\)](#) argue that jobs’ skill requirements have increased during the post-Great Recession period; [Deming and Kahn \(2017\)](#) find that firms that post ads with a high frequency of words related to social and cognitive skills have higher labor productivity and pay higher wages.⁸ Our contribution relative to this second literature is to extend the analysis of job ad text to the pre-internet era, spanning a much longer horizon and a key period of rising inequality and occupational change. We also apply tools from Natural Language Processing — tools that to our knowledge have had limited use in economics research — to extend our word-based task categories to include synonyms of task-related words and to limit our analysis’ sensitivity to changes in word meaning over time.

The rest of the paper is organized as follows. Section 2 outlines the construction of our data set of occupations and their skill and task content. We compare this new data set to existing data sources in Section 3. In Section 4, we document changes in the distributions of occupational tasks. Section 5 links task changes to changes in the earnings distribution, first in a reduced-form exercise and then with the aid of a structural model. Section 6 reviews our results and suggests areas for future research.

2 A New Data Set of Occupational Characteristics

In this section, we discuss the construction of our structured database of occupational characteristics. The primary data sets are raw text files, purchased from ProQuest and originally published in the *New York Times* (from 1940 to 2000), *Wall Street Journal* (from 1940 to 1998), and *Boston Globe* (from 1960 to 1983). We extract from the newspaper text the frequency of words related to occupations’ skill requirements and their work activities. We complement these text files with a data set purchased from Economic Modeling Specialists International (EMSI). The first step in our approach is to clean and process the raw newspaper data. Then, we map job ad titles to Standard Occupational Classification (SOC) codes. Finally, we map job ad text into tasks, by grouping sets of words according to their meaning. Once we describe these procedures, we present some simple descriptive statistics from our

⁷Text analysis has been fruitfully applied in other branches of economics. [Gentzkow and Shapiro \(2010\)](#) study the text from newspapers and from the Congressional Record to construct an index of newspapers’ partisan slant. [Hoberg and Phillips \(2016\)](#) use the text from publicly-traded firms’ filings to the Securities and Exchange Commission to classify industries and to draw insights about the identities of firms’ competitors.

⁸One paper that uses newspaper job ads to study worker-firm matching is [DeVaro and Gurtler \(2018\)](#), which documents that before 1940 both job seekers and firms posted advertisements to match with one another, and that after 1940 firms have been the primary party posting ads.

constructed data set.

2.1 Processing the Newspaper Text Files

The newspaper data are stored as raw text files, which ProQuest has produced using an algorithm that converts images of newspapers into text files. The raw text files that ProQuest has provided allow us to isolate the subset of text that come from advertisements, but do not allow us to directly identify job ads from other types of advertisements. Nor does the text indicate when one job ad ends and another one begins. Therefore, in processing the ProQuest text files, we must i) identify which advertisements comprise vacancy postings, ii) discern the boundaries between vacancy postings, and iii) identify the job title of each vacancy posting. In addition, as much as possible, we attempt to undo the spelling mistakes induced by ProQuest’s imperfect transcription of the newspaper text. Appendix C.1 describes our procedure for performing i). Appendix C.2 describes steps ii) and iii). In the same appendix, we present an example — using the text which ProQuest has provided us corresponding to three individual job ads from the November 4, 1979 *Boston Globe* — of the performance of our text-processing procedure. Overall, our procedure allows us to transform unstructured text into a set of 6.6 million distinct job ads linking job titles to job ad text. Our procedure furthermore is able to undo a portion of the error induced by ProQuest’s optical character recognition software.

2.2 Grouping Occupations by SOC Code

Our next step is to consolidate the information in our vacancy postings to characterize occupations and their corresponding attributes into a small number of economically meaningful categories. In the newspaper text, postings for the same occupation appear via multiple distinct job titles. For example, vacancy postings for registered nurses will be advertised using job titles which include “iv nurse,” “icu nurse,” or “rn coordinator.” These job titles should all map to the same occupation — 291141 using the BLS Standard Occupational Classification (SOC) system.

From our list of job titles, we apply a *continuous bag of words* (CBOW) model to identify the ad’s SOC code. Roughly put, this CBOW model allows us to find synonyms for words or phrases. The model is based on the idea that words or phrases are similar if they themselves appear (in text corpora) near similar words. For example, to the extent that “iv nurse,” “icu nurse,” and “rn coordinator” all tend to appear next to words like “patient,” “care,” or “blood” one would conclude that “rn” and “nurse” have similar meanings to one another. For additional background on CBOW models, and details on our implementation, see Appendix C.3. EMSI has provided us a data set of the text from online job ads, originally posted between October 2011 and March 2017. These ads contain a job title and text describing the job characteristics and requirements. We use the online job postings from two of these

months, January 2012 and January 2016, plus all of the text from our newspaper data to construct our CBOW model.

Our CBOW model is useful for our purpose when applied in combination with O*NET’s Sample of Reported Titles and list of Alternate Titles. Once we have estimated the CBOW model, for each job title \mathcal{N} in our newspaper text, we search for the job title \mathcal{O} among those in the O*NET Sample of Reported Titles and list of Alternate Titles that is most similar to \mathcal{N} .⁹ Since each of the job titles in the O*NET Sample of Reported Titles and list of Alternate Titles has an associated SOC code, we can obtain the SOC code for any job title in our newspaper text. As an example, the job title “rn coordinator” — a title from our newspaper data — is closest to the O*NET Title “Registered Nurse Supervisor,” the latter which has an associated SOC code of 291141. Based on this, we identify 291141 as the SOC code for “rn coordinator.” In this manner, we retrieve these SOC codes on all of the job titles which appear at least twice in our newspaper text. This procedure yields SOC codes for 4.2 million job ads.

2.3 Eliciting Skill- and Task-Related Information

Within the body of our job ads, we map similar words to a common task or skill. For example, mathematical skills could appear in job ads using the words “mathematics,” “math,” or “quantitative.” To study occupations’ evolving skill requirements and task content, it is necessary to categorize not only job titles, but also these occupational characteristics into a manageable number of groups. We follow four approaches, which we explain next.¹⁰

Our main classification follows that of [Spitz-Oener \(2006\)](#) who, in her study of the changing task content of German occupations, groups survey questionnaire responses into five categories: *nonroutine analytic*, *nonroutine interactive*, *nonroutine manual*, *routine cognitive*, and *routine analytic*.¹¹ In our main application of these categories, we begin with the list of words related to each of her five tasks. For each task, we augment the list with words

⁹The CBOW model associates each word and phrase with a vector, with elements in the vector describing the contexts in which the word or phrase appears. The similarity between job titles \mathcal{O} and \mathcal{N} equals the cosine similarity of the vectors associated with these two titles.

¹⁰Throughout this paper, we interpret the words as accurate representations of the positions the firms seek to fill. We cannot measure the extent to which firms may misrepresent or perhaps euphemize the tasks of the job to attract workers. A similar consideration, however, is also relevant for survey-based measures of tasks, where respondents may or may not accurately answer questions about their job’s tasks ([Autor, 2013](#)). Our analysis is unaffected by level differences job descriptions’ accuracy, and would only be affected by trends in the representation of jobs over time.

¹¹The data set used in [Spitz-Oener \(2006\)](#) is a questionnaire given to West German workers. Building on her mapping from survey question titles to task categories, we search for the following sets of words for each category: 1) nonroutine analytic: analyze, analyzing, design, designing, devising rule, evaluate, evaluating, interpreting rule, plan, planning, research, researching, sketch, sketching; 2) nonroutine interactive: advertise, advertising, advise, advising, buying, coordinate, coordinating, entertain, entertaining, lobby, lobbying, manage, managing, negotiate, negotiating, organize, organizing, presentation, presentations, presenting, purchase, sell, selling, teaching; 3) nonroutine manual: accommodate, accommodating, accommodation, renovate, renovating, repair, repairing, restore, restoring, serving; 4) routine cognitive: bookkeeping, calculate, calculating, correct, correcting, measurement, measuring; 5) routine manual: control, controlling, equip, equipment, equipping, operate, operating.

whose meanings are similar to those in the original list, where similarity is determined by our CBOW model. This is our primary classification, and we use it in each empirical exercise that follows in the paper. In addition, as a robustness check, we consider a narrower mapping between categories and words, one which only relies on [Spitz-Oener \(2006\)](#)'s definitions as enumerated in footnote 11. Including similar words based on our CBOW model has its advantages and disadvantages. On the one hand, the continuous bag of words model has the advantage of accounting for the possibility that employers' word choice may differ within the sample period.¹² On the other hand, there is a danger that the bag of words model will identify words as synonymous even if they are not.

We also consider three complementary task classifications, for the purpose of i) exploring the robustness of our results to our primary choice of classification; ii) comparing our text-based measures with widely-used survey-based measures; and iii) connecting our main results to those in the literature. First, with the aim of validating our data set, we map our text to O*NET's work styles, skills, knowledge requirements, and work activities (corresponding to O*NET Elements 1C, 2A and 2B, 2C, and 4A, respectively). For each O*NET Element, we begin by looking for words and phrases related to the O*NET Title and words within the O*NET Element Description. We then append to our initial lists of words and phrases synonyms from our continuous bag of words model.

Second, for the purpose of exploring the implications of changes in tasks for the earnings distribution and connecting to the existing literature that relies on fixed task measures, we map our text to tasks used in [Firpo, Fortin, and Lemieux \(2014\)](#). Firpo, Fortin, and Lemieux categorize O*NET work activities and contexts into five groups: Information Content, Automation/Routine, Face-to-Face Contact, On-Site Job, and Decision-Making.¹³ Our last mapping is to skills in [Deming and Kahn \(2017\)](#)'s study of the relationship between firms' characteristics and the skill requirements in their vacancy postings. We explore these measures in Appendices [D.4](#) and [D.5](#) to provide complementary results.

¹²For instance, even though "creative" and "innovative" largely refer to the same occupational skill, it is possible that their relative usage among potential employers may differ within the sample period. This is indeed the case: Use of the word "innovative" has increased more quickly than "creative" over the sample period. To the extent that our ad hoc classification included only one of these two words, we would be mis-characterizing trends in the O*NET skill of "Thinking Creatively." The advantage of the continuous bag of words model is that it will identify that "creative" and "innovative" as synonyms because they appear in similar contexts within job ads. Hence, even if employers start using "innovative" as opposed to "creative" part way through our sample, we will be able to consistently measure trends in "Thinking Creatively" throughout the entire period. A second advantage of our CBOW model is that it allows us to partially undo the transcription errors generated in ProQuest's image scanning. Our CBOW algorithm, for example, identifies "adverhslng" as synonymous "advertising."

¹³See Appendix Table A.2 of [Firpo, Fortin, and Lemieux \(2014\)](#) for the mapping between their task groups and O*NET work activities and work contexts. Since our constructed data set includes only work activities, our corresponding measures of [Firpo, Fortin, and Lemieux \(2014\)](#)'s O*NET groups are based only on work activity variables, and since the Automation/Routine task group is defined only by O*NET work contexts, we will not be able to measure this variable.

Table 1: Common Occupations

Job Title		6-Digit SOC Occupations		4-Digit SOC Occupations	
Description	Count	Description	Count	Description	Count
Secretary	117.1	436012: Legal Secretary	178.5	4360: Secretary	374.4
Sales	56.0	439022: Typist	177.8	4390: Other Admin.	284.2
Assistant	53.7	414012: Sales Rep.	135.2	1320: Accountant	204.0
Accounting	50.9	132011: Accountant	128.0	4330: Financial Clerks	191.7
Clerk	49.9	412031: Retail Sales	110.2	4140: Sales Rep.	158.4
Typist	49.7	436014: Secretary	94.8	1511: Computer Sci.	133.9
Salesperson	42.2	436011: Exec. Secretary	88.6	4120: Retail Sales	131.3
Engineer	41.8	291141: Nurse	81.3	1720: Engineers	107.8
Manager	41.1	433021: Bookkeeper	80.7	2911: Nurse	107.1
Bookkeeper	40.5	411011: Sales Supervisors	70.7	4340: Record Clerks	107.0

Notes: This table lists the top ten job titles (columns 1-2), the top 10 6-digit SOC codes (columns 3-4), and the top 10 4-digit SOC codes (columns 5-6) in the *Boston Globe*, *New York Times*, and *Wall Street Journal* data. The counts are given in thousands of newspaper job ads.

2.4 Descriptive Statistics

Using the newspaper text, our algorithm from Section 2.1 results in a data set with 6.6 million vacancy postings.¹⁴ Among these vacancy postings, we have been able to retrieve a SOC code for 4.2 million ads. Table 1 lists the top occupations in our data set.¹⁵ The first two columns list common job titles among the 6.6 million total vacancy postings, while the last four columns present the top SOC codes.¹⁶ Across the universe of occupations, our newspaper data represents a broad swath of Management, Business, Computer, Engineering, Life and Physical Science, Healthcare, Sales, and Administrative Support occupations, but it under-represents Construction occupations and occupations related to the production and transportation of goods. See Appendices A and B for an analysis of the representativeness of our newspaper data relative to the decennial census and CPS (Ruggles, Genadek, Goeken, Grover, and Sobek, 2015.) Even though our newspaper text underrepresents certain blue collar occupations, there are still a considerable number of ads that we can map to each 4-digit SOC code at points throughout our sample period.

¹⁴This 6.6 million figure excludes vacancy postings for which we cannot identify the job title or which contain a substantial portion, 35 percent or greater, of misspelled words. We also exclude ads with fewer than 15 words.

¹⁵There are two types of job titles for which we do not find an associated SOC code. First, certain job titles, such as “trainee” or “personnel secretary” for which the title is either uninformative (in the case of trainee) or refers to the person to whom job applications are usually sent (in the case of personnel secretary). Second, we do not attempt to match the job titles which appear only once in the newspaper text. Matching these job titles individually would take an inordinately long amount of time.

¹⁶Marinescu and Wolthoff, 2016 document that many job titles contain multiple words. Even though the top job titles in Table 1 are single word, most job ads -- 71 percent -- contain multi-word job titles. To the extent that newspaper space is more scarce than space within online job ads, newspaper job titles will be shorter than the job ads within Marinescu and Wolthoff’s analysis.

Table 2: Top Occupations by [Spitz-Oener \(2006\)](#) Task Category

Nonroutine Analytic			Nonroutine Interactive		
1721: Engineers	72.6	15.8	1120: Sales Managers	48.8	18.1
1720: Engineers	107.8	14.9	4140: Sales Rep., Wholesale/Manuf.	158.4	14.2
1710: Architects	13.8	14.4	4120: Retail Sales	131.3	11.7
5530: Military Forces	0.8	13.2	4130: Sales Rep., Services	78.2	11.6
1520: Math. Science	9.7	12.9	4110: Supervisors of Sales	101.4	11.5
Nonroutine Manual			Routine Cognitive		
4930: Vehicle Mechanics	28.2	5.6	4330: Financial Clerks	191.7	5.9
4920: Electrical Mechanics	18.1	3.4	4391: Other Admin. Support	32.9	4.1
4990: Other Maintenance	30.7	3.2	4340: Record Clerks	107.0	2.6
4910: Maintenance Superv.	3.5	3.2	4390: Other Admin. Support	284.2	2.2
4721: Construction Trades	12.2	3.0	4320: Communic. Equip. Operators	11.5	2.0
Routine Manual					
5140: Metal and Plastic	24.5	4.1			
5141: Metal and Plastic	12.6	1.4			
4540: Logging	11.1	1.3			
4930: Vehicle Mechanics	28.2	1.3			
3940: Funeral Service	0.2	1.2			

Notes: This table lists the top five 4-digit occupations according to the frequency with which different activity-related words are mentioned. Within each panel, the first column gives the SOC code and title; the second column gives the number of job ads in our data set (in thousands); and the final column gives the frequency (mentions per 1000 job ad words) of task-related words.

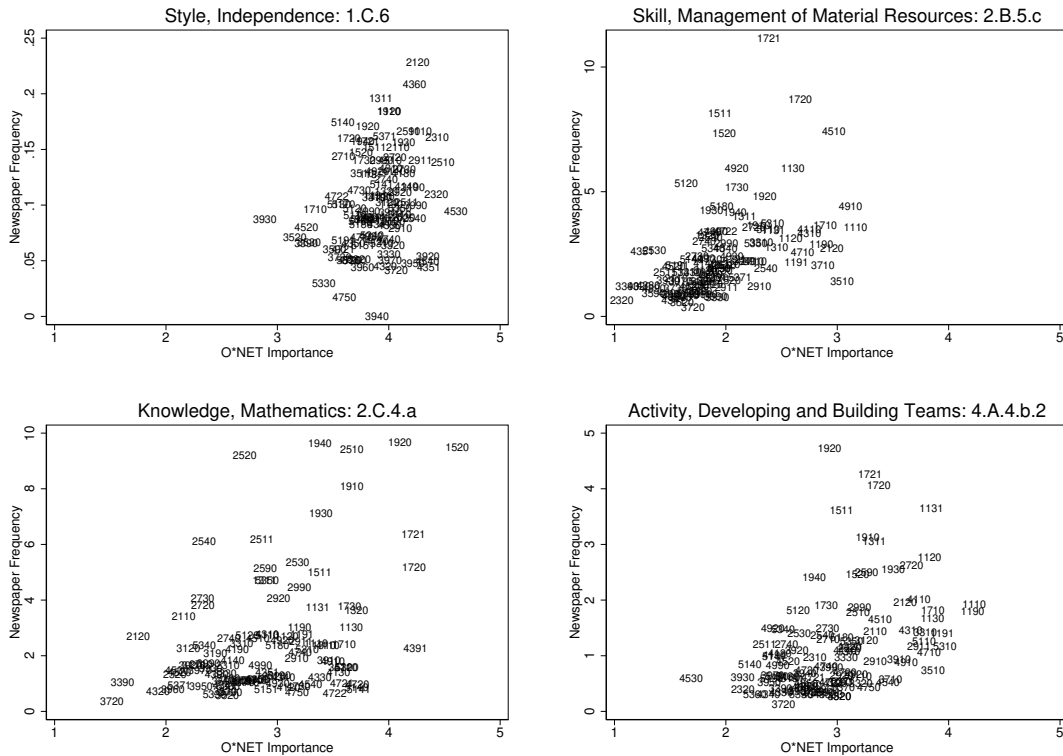
Table 2 presents, for each task in [Spitz-Oener \(2006\)](#)'s classification, the most task-intensive occupations. Occupations which are intensive in nonroutine analytic tasks are concentrated in Architectural and Engineering occupations and Life, Physical, and Social Science occupations. Management and Sales occupations mention nonroutine interactive tasks frequently, while customer service and maintenance related occupations have high nonroutine manual task intensities. Routine cognitive and routine manual task-related words are mentioned frequently in advertisements for clerical and production-related positions.

3 Comparison of the New Data Set to Existing Data Sets

Before exploring trends in occupational task content and the implications for the distribution of earnings, we briefly compare our new data source to those previously used in the literature. Our goal is to demonstrate the usefulness of newspaper text for measuring the task content of occupations.

First, Figure 1 relates the O*NET Importance measure to newspaper keyword frequencies. Each panel 1 presents a comparison for a different O*NET Element: one work style (Independence), one skill (Management of Material Resources), one knowledge requirement

Figure 1: O*NET Importance Measures and Newspaper Keyword Frequencies



Notes: Each panel corresponds to one O*NET element. In each panel, each point represents a SOC code. The value of the x-axis represents the O*NET Importance measure (from version 22.1 of the O*NET database). The y-axis measures the number of keyword appearances per 1000 job ad words, using data from the *Boston Globe*, *New York Times*, and *Wall Street Journal*.

(Mathematics), and one work activity (Developing and Building Teams). Within each panel, each data point represents a single 4-digit SOC occupation: For example, the “4510” (the code for Supervisors of Farming, Fishing, and Forestry Workers) in the top right panel indicates that the O*NET Importance of the skill of “Management of Material Resources” is 3.0 (on a scale from 1 to 5), while in the newspaper data, we detect 7.4 Management of Material Resources related keywords per thousand (correctly spelled) job ad words. The correlations (weighted by the number of vacancy postings in our newspaper data) in these four plots are 41 percent, 53 percent, 48 percent, and 49 percent, respectively.¹⁷

The four relationships depicted in Figure 1 are broadly representative of the concordance between O*NET Importance measures and our vacancy postings’ keyword frequencies: The correlation between our measures and existing O*NET measures of occupational work styles, skill, knowledge requirement, and activity measures are, for the most part, in the 0.40 to 0.65 range, and are somewhat higher for knowledge requirements, skills, and activities (where

¹⁷Across all 125 O*NET Elements, the unweighted correlations are lower by 3 percentage points on average.

the mean correlations are 0.57, 0.52, and 0.47, respectively) than for work styles (where the mean correlation is 0.30).¹⁸

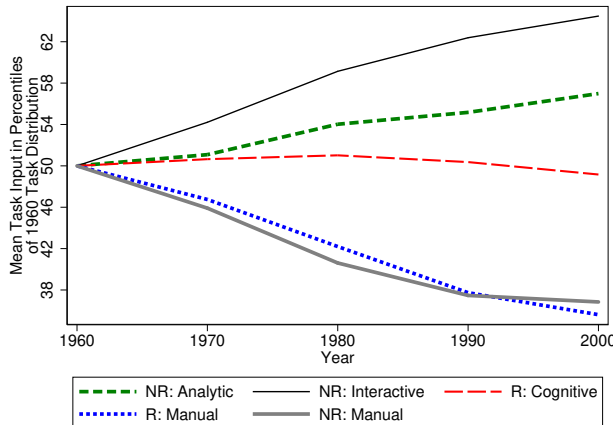
As a second check of our new data set, we examine whether our newspaper-based task measures give a portrayal of between-occupation shifts similar to that in the preceding literature. To do so, we replicate Figure 1 of [Autor, Levy, and Murnane \(2003\)](#), which reports a key finding in the task literature. In this exercise, industry-gender-education groups are ranked according to the task scores of the occupations in which this group works.¹⁹ Then, taking the 1960 distribution of employment as the baseline year, Autor, Levy, and Murnane compute (for each of the five tasks, individually) the employment-weighted mean of the percentiles of the task distribution at different points in time from 1960 to 1998. According to Figure 1 of [Autor, Levy, and Murnane \(2003\)](#), nonroutine analytic and interactive task content increases by 8.7 and 12.2 percentiles, respectively, over this period. The aggregate nonroutine manual, routine cognitive, and routine manual task content decreases by 8.7, 5.6, and 0.8 percentiles. Their figure demonstrates that there has been substantial between-occupation shifts away from routine task intensive occupations.

In Figure 2, we perform the same exercise, now using our newspaper-based nonroutine and routine task measures. Like [Autor, Levy, and Murnane \(2003\)](#), we compute percentiles of demographic groups' task averages based on their 1977 task content. We then compute the mean employment-weighted percentile for each year between 1960 and 2000, taking 1960 employment shares as the baseline. Nonroutine analytic and interactive task content increases by 7.0 and 14.5 percentiles, respectively. Moreover, the aggregate nonroutine manual, routine cognitive, and routine manual task measures decrease by 13.2 percentiles, 0.8 percentiles, and 14.4 percentiles, respectively. Overall, the decade-by-decade growth rates are similar when using our newspaper data or the DOT: Pooling across the five task measures and four decades, the correlation between the two sets of growth rates equals 0.62. The main difference between the data sources is that the estimated between-occupation shifts away from routine manual tasks are more pronounced according to our newspaper-based task measures, while our measured shift away from routine cognitive tasks is smaller relative to the DOT-based measures. This exercise indicates that while our main empirical analysis,

¹⁸While we view O*NET as a useful and reliable benchmark, it too has its issues, which extend beyond its inability to track within-occupation changes in job characteristics over long time horizons. In their review of the design of the O*NET data collection program, the [National Research Council \(2010\)](#) identify several aspects of O*NET which may limit its usefulness as a research tool. Summarizing these issues, [Autor \(2013\)](#) writes that both the Dictionary of Occupational Titles and O*NET “job content measures are often vague, repetitive, and constructed using ambiguous and value-laden scales that are likely to confuse respondents” (p. 191). We should neither expect nor hope that our measures exactly align with O*NET measures, but we interpret the correlations as reassuring evidence that the newspaper text is a valuable source of task data.

¹⁹These task scores come from specific questions within the Dictionary of Occupational Titles (DOT). According to [Autor, Levy, and Murnane \(2003\)](#), GED Math Scores are a measure of nonroutine analytic tasks; the Direction, Planning, and Control measure corresponds to nonroutine interactive tasks; Setting Limits, Tolerances, and Standards is a measure of routine cognitive tasks; Finger Dexterity is a measure of routine manual tasks; and Eye, Hand, and Foot Coordination is a measure of nonroutine manual tasks.

Figure 2: Comparison to [Autor, Levy, and Murnane \(2003\)](#), Figure 1



Notes: Industry-gender-education groups are ranked by their task content, as of 1960. The plotted task percentiles in the succeeding years are the employment weighted task percentiles. There are 2440 cells, representing the combination of two genders, five education groups (<HS, HS, Some College, College, Post-graduate) and 244 industries (defined by the census ind1990 variable).

in the following two sections, will point to within-occupation shifts as an important source of changes in the economy’s task content, it is also consistent with one of the foundational results of the task literature, namely that there are substantial between-occupation shifts from routine to nonroutine tasks.

In Appendices [D.1](#), [D.2](#), and [D.3](#), we perform three exercises, each with the aim of further supporting our paper’s data contribution. First, we document that i) there is no more than a weak, marginally significant trend in average ad length, and ii) there are no meaningful trends in the share of ad words which do not appear in an English dictionary. Such trends, if they were present and important in the data, would be suggestive of trends in measurement error within our sample period (due to, for example, changing typographical conventions or improvements in image quality). At least based on this exercise, we cannot detect time-varying measurement error.

Second, building on [Figure 2](#), we compare our data set’s task measures with the analogous measures based on the 1977 and 1991 vintages of the Dictionary of Occupational Titles. We report that, across occupations, our task measures broadly align with those in the Dictionary of Occupational Titles. However, the portrayals of within-occupation task trends — comparing our newspaper data with the DOT — are starkly different. In contrast to what our newspaper data indicate, the DOT data set indicates that there has been a broad shift within occupations away from nonroutine analytic tasks towards routine manual tasks. However, in [Appendix D.2](#) we provide evidence that the DOT is ill suited to measurement of within occupation changes in tasks, corroborating the characterization made by [Autor, Levy, and Murnane \(2003\)](#). For many occupations, the DOT’s measures were not updated between the 1977 and 1991 vintages. Suggestive of this, the correlation across occupations

in the GED Math scores across the 1977 and 1991 vintages of the DOT equals 0.98. On the other hand, since newspaper text are continuously updated, our data set is capable of detecting within-occupation changes in tasks.

Third, using a five percent sample of ads which were posted on-line and collected by EMSI (totaling 7.6 million ads), we compare the task content of ads which were posted for jobs in the New York City and Boston metro areas to jobs based elsewhere. In particular, we examine whether, within occupations, the task content is systematically different in Boston and New York City compared to the rest of the U.S. We find that job ads in the New York City and Boston metro areas are indeed statistically different, but only slightly so (the difference amounts to at most 0.03 standard deviations of each of these task measures.) The aim of this exercise is to gauge the representativeness of our sample New York City and Boston newspapers. So, while we cannot examine the representativeness of the New York City and Boston newspapers' ads directly, we find in our online data that job ads in New York City and Boston, for a given occupation, are not materially different from those posted elsewhere.

4 Trends in Tasks

In this section, we document trends in occupational tasks from 1960 to 2000. The main results from these exercises are that i) between the 1960s and 1990s words related to nonroutine interactive and analytic tasks have increased in frequency, while words related to routine manual and cognitive tasks have decreased in frequency, and ii) a majority of these changes are due to changes within occupations, rather than changes in employment shares across occupations. Lastly, we compare trends for two particular groups of occupations and show that our results resonate with previous findings in the literature.

4.1 Overall Trends

Table 3 presents changes in task-related keywords, grouped according to the definitions introduced in [Spitz-Oener \(2006\)](#). In each of the five panels within this table, the first row presents the mean number of task-related words per thousand ad words, at the beginning of the sample, in 1960. We call this \bar{T}_{1960} . In the remaining rows of each panel, we display changes in the task-related words. The measure in the first column of each panel, which we interpret as the aggregate task content in the economy, presents average mentions in each occupation, using census employment shares as occupation weights. According to this measure, mentions of nonroutine tasks increased between 1960 and 2000 by 57 log points for analytic tasks (an increase of 2.61 mentions per thousand ad words, from a baseline of 3.43) and 42 log points for nonroutine interactive tasks. Conversely, the keyword frequency for words related to routine manual tasks substantially declined, decreasing from 0.78 to 0.06

mentions per thousand ad words. The decline of routine cognitive tasks is also considerable, going from 1.23 to 0.76 mentions per thousand words.

These changes reflect both between-occupation and within-occupation changes in task-related keywords. To assess the relative importance of between- versus within-occupation forces in shaping these trends, we decompose changes in the aggregate content of each task according to the following equation:

$$\bar{T}_t = \bar{T}_{1960} + \sum_j \vartheta_{j,1960} \left(\tilde{T}_{jt} - \tilde{T}_{j,1960} \right) + \sum_j (\vartheta_{j,t} - \vartheta_{j,1960}) \tilde{T}_{jt}. \quad (1)$$

In this equation, \tilde{T}_{jt} is a measure of task-related word frequency in postings for occupation j in year t . The ϑ_{jt} terms measure the share of workers in occupation j at time t according to the decennial census, while \bar{T}_t denotes the share-weighted average frequency of the task-related word at time t .²⁰ On the right-hand side of Equation 1, the first sum captures shifts in the overall keyword frequencies due to within-occupation changes in task-related word mentions. The second sum captures shifts in the share of workers across occupations. We use a 4-digit SOC classification to perform this decomposition separately for each of the five tasks introduced in [Spitz-Oener \(2006\)](#). The second and third columns of Table 3 list changes in \bar{T}_t due to the within- and between- components of Equation 1. The final column gives the proportion of the overall changes in keyword frequencies due to the “Within” components.

These columns indicate that 92 percent of the increase in nonroutine analytic tasks and 86 percent of the increase in nonroutine interactive tasks are due to within-occupation rather than between-occupation shifts in tasks. Furthermore, within-occupation shifts are an important contributor to aggregate changes in the 1970s, 1980s, and 1990s.²¹ Similarly, a large portion of the decline in routine manual task content occurred within rather than between occupations, not only when looking over the 40 year period, but also when looking within each decade. For routine cognitive tasks, within-occupation shifts are also a large contributor of the decline in overall routine cognitive task content in the 1960s and 1970s. The within-versus-between decomposition does not paint a clear picture for the 1980s or 1990s for this task measure.²² Overall, for the median task, within-occupation shifts account for

²⁰Throughout this section and Section 5 we draw from the sample of full time workers — workers who were between the age of 16 and 65, who work for wages, who worked at least 40 weeks in the preceding year, and who have non-imputed gender, age, occupation, and education data. We construct our own mapping between SOC codes and Census occ1990 codes by taking the modal SOC code for each occ1990 code (drawing on a sample of all workers in the 2000 census public use sample, and the 2007 and 2013 American Community Survey for which both variables are measured). From our full-time worker sample, we take ϑ_{jt} as the share of workers who work in SOC occupation j in decennial census years.

²¹In certain decades, the “Within Share” is either greater than 1 or less than 0. This can occur in periods in which within-occupation and between- occupation shifts in task content move in opposite directions.

²²The “Within Shares” reported in the final columns of Table 3 are largely consistent with Table 5 of [Spitz-Oener \(2006\)](#). There, [Spitz-Oener \(2006\)](#) calculates that nearly all of the changes in West German task content, between 1979 and 1999, occurred within rather than between occupations.

Table 3: Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	A. Nonroutine Analytic				B. Nonroutine Interactive			
1960 Level	3.43 (0.08)				4.95 (0.05)			
1960-1970	0.26 (0.07)	0.14 (0.01)	0.13 (0.07)	0.48 (0.23)	-0.15 (0.05)	0.17 (0.01)	-0.32 (0.05)	2.09 (0.93)
1970-1980	0.54 (0.04)	0.21 (0.01)	0.34 (0.04)	0.62 (0.04)	0.81 (0.03)	0.30 (0.01)	0.51 (0.03)	0.63 (0.01)
1980-1990	0.77 (0.04)	0.12 (0.02)	0.64 (0.04)	0.84 (0.03)	1.02 (0.04)	0.10 (0.02)	0.93 (0.05)	0.90 (0.02)
1990-2000	1.04 (0.11)	-0.26 (0.15)	1.31 (0.20)	1.25 (0.13)	0.93 (0.12)	-0.20 (0.15)	1.12 (0.24)	1.21 (0.15)
1960-2000	2.61 (0.14)	0.20 (0.15)	2.41 (0.23)	0.92 (0.06)	2.61 (0.15)	0.37 (0.16)	2.24 (0.27)	0.86 (0.06)
	C. Nonroutine Manual				D. Routine Cognitive			
1960 Level	1.00 (0.03)				1.23 (0.02)			
1960-1970	0.03 (0.02)	0.03 (0.00)	0.00 (0.03)	0.13 (1.56)	-0.25 (0.02)	0.04 (0.00)	-0.30 (0.02)	1.17 (0.02)
1970-1980	-0.06 (0.01)	-0.11 (0.01)	0.05 (0.01)	-0.91 (0.60)	-0.13 (0.01)	-0.01 (0.00)	-0.12 (0.01)	0.96 (0.02)
1980-1990	-0.08 (0.02)	-0.03 (0.01)	-0.05 (0.02)	0.61 (0.14)	-0.04 (0.01)	-0.04 (0.01)	0.00 (0.02)	-0.10 (0.54)
1990-2000	-0.02 (0.04)	0.03 (0.03)	-0.06 (0.05)	2.38 (5.21)	-0.05 (0.06)	-0.14 (0.14)	0.09 (0.20)	-1.80 (18.44)
1960-2000	-0.13 (0.06)	-0.08 (0.04)	-0.05 (0.07)	0.38 (0.90)	-0.47 (0.06)	-0.14 (0.15)	-0.33 (0.20)	0.70 (0.41)
	E. Routine Manual							
1960 Level	0.78 (0.03)							
1960-1970	-0.20 (0.03)	-0.03 (0.00)	-0.17 (0.03)	0.88 (0.03)				
1970-1980	-0.23 (0.01)	-0.05 (0.00)	-0.17 (0.01)	0.77 (0.02)				
1980-1990	-0.20 (0.01)	0.02 (0.01)	-0.23 (0.01)	1.11 (0.04)				
1990-2000	-0.09 (0.02)	0.03 (0.02)	-0.13 (0.01)	1.35 (0.37)				
1960-2000	-0.72 (0.03)	-0.02 (0.02)	-0.70 (0.03)	0.97 (0.03)				

Notes: Occupations are defined using the 4-digit SOC classification. Within each panel, we compute keyword frequencies (mentions per 1000 job ad words) at the beginning of the sample (first row), decade-by-decade changes (second through fifth rows), and cumulative changes over the 40 year period (sixth row). In these averages, occupation shares are given by the number of full-time workers in the decennial census. Terms within parentheses give bootstrapped standard errors, based on re-sampling ads from our newspaper text 40 times.

86 percent in economy-wide task content.

Sensitivity Analysis

In Appendix D.5 we consider the sensitivity of the results given in Table 3 to the mapping of words to tasks and to the level of detail of the occupation codes used.

First, we recompute Table 3 with Spitz-Oener (2006)’s original mapping between tasks and words (i.e., excluding the words which we have appended from our continuous bag of words model). Second, we consider two alternate measures of occupational characteristics, one introduced by Firpo, Fortin, and Lemieux (2014) and the other by Deming and Kahn (2017). Using each of these three alternate measures of occupational characteristics, the predominant share of the overall changes in occupational characteristics occurs within rather than between 4-digit SOC codes.

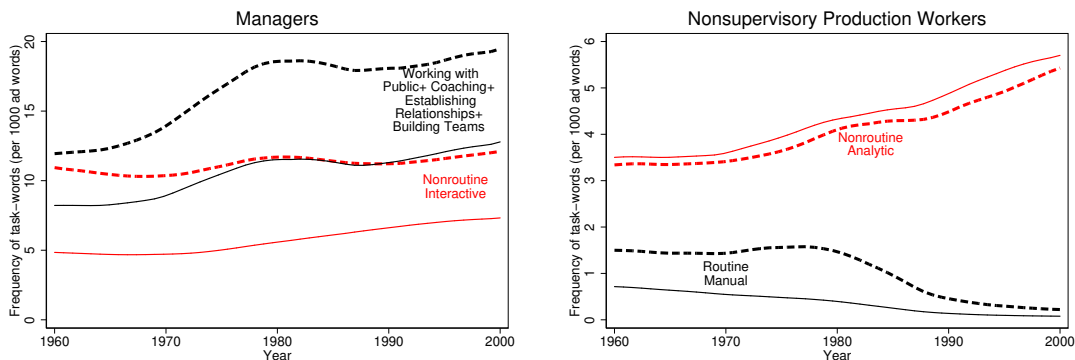
The extent to which between-occupation changes are responsible for overall changes in keyword frequencies may potentially be sensitive to the coarseness of occupation definitions. If occupations are coarsely defined, one will tend to estimate that between-occupation changes are relatively unimportant. In a second robustness check, we re-estimate Equation 1 first using 6-digit SOC codes to classify occupations and alternatively using individual job titles to classify occupations. Instead of a median within share of 0.86, which we obtain from averaging over the “1960 to 2000” cell within the final columns of Table 3, we obtain a median within share of 0.75 with a 6-digit classification and 0.61 with a job-title-based classification. For all three classifications, within-occupation changes are a primary source of the overall shift in task content.

Finally, in the same appendix, we investigate a potential limitation of our approach, namely that we are using job ads (which characterize newly formed jobs) to measure the entire stock of jobs existing at that point in time. Using a perpetual inventory type method, we construct a measure of the stock of each task in each occupation, then recompute the overall and within-occupation shifts in task content. According to this exercise, the within shares have a median value of 0.86, equal to that in our benchmark calculation.

4.2 Narratives of Occupational Change

In this section, we present two vignettes that demonstrate how individual occupation groups have evolved over our sample period. (In Appendix D.6, we discuss a third example, motivated by Autor (2015)’s account of changes experienced by bank tellers: the changing nature of work for office clerical workers.) Our goal is to provide concrete, illustrative examples of occupational change through the lens of our task and skill measures. We emphasize that these examples represent a portrait of long-run occupational change that was previously unobserved by researchers.

Figure 3: Task Measures



Notes: We apply a local polynomial smoother. Averages across all occupations are depicted as solid lines. In the left panel, managerial occupations (with a SOC code between 1100 and 1199) are plotted as dashed lines. In the right panel, non-supervisory production occupations have an SOC code between 5120 and 5199 and are plotted as dashed lines.

In the left panel of Figure 3, we present two separate task measures for managerial occupations (in thick, dashed lines) and all occupations (in thin, solid lines). Between 1960 and 2000, the frequency of words related to nonroutine interactive tasks in managerial occupations increased modestly. This modest trend reflects a small increase in the number of words related to selling — which are common in managerial occupations and exceptionally common in Sales Manager occupations — and a large increase in words that the [National Research Council \(1999\)](#) has emphasized in their characterization of the changing nature of managerial work. Summarizing the contemporaneous literature, the [National Research Council \(1999\)](#) writes that trends in managerial work involve “the growing importance of skills in dealing with organizations and people external to the firm, the requirement that [managers] ‘coach’... and facilitate relations between workers” (pp. 137-138). Motivated by this characterization, we also plot trends in the mentions of four O*NET work activities: Working with the Public (O*NET Element 4.A.4.a.3), Establishing and Maintaining Relationships (4.A.4.a.4), Building Teams (4.A.4.b.2), and Coaching (4.A.4.b.5). Mentions of these four activities nearly doubles, from 11.5 to 19.5 mentions per thousand job ad words, increasing more quickly than for the workforce as a whole.²³ In sum, while tasks associated with building and maintaining interpersonal relationships have always been central to managerial occupations, the importance of such tasks has widened since 1960.

Second, compared to the beginning of the sample period, the frequency of routine manual tasks has declined considerably, particularly in non-supervisory production occupations: For such workers, mentions of routine manual tasks fell from 1.5 to 0.2 mentions per thousand words. The right panel of Figure 3 presents these trends along with changes in the frequency

²³While it is true that some of these changes reflect trends in the relative sizes of different managerial occupations, in Appendix D.6 we plot changes in task intensities within 4-digit SOC occupations. The results look quite similar.

of nonroutine analytic task related words. Nonroutine analytic task keywords have been increasingly mentioned in job ads for production workers. The trends in keyword frequencies in this figure are consistent with case studies of manufacturers' adoption of new information technologies (e.g., [Bartel, Ichniowski, and Shaw, 2007](#)). These new technologies substitute for workers who were previously performing routine manual tasks. The surviving production workers are those who have high levels of technical and problem-solving skills.

5 Implications for the Earnings Distribution

In this section, we use our new time-varying task measures to explore the implications of changes in occupations' task content for the earnings distribution. First, we bring our measures of occupations' task content to the decomposition methods of [Fortin, Lemieux, and Firpo \(2011\)](#). The goal of this exercise is to determine which occupational characteristics account for changes in the distribution of earnings between 1960 and 2000. Next, in [Section 5.2](#), we develop a framework for interpreting occupations as a bundle of tasks. We embed this framework into a quantitative general equilibrium model of occupational sorting based on comparative advantage (akin to [Heckman and Sedlacek, 1985](#), [Heckman and Scheinkman, 1987](#), or more recently [Burstein, Morales, and Vogel, 2015](#)). We estimate this model and then use it to quantify the impact of changes in the demand for tasks on earnings inequality.

We view the two approaches as complementary methods for understanding the sources of increasing inequality, each approach with its own advantages and disadvantages. The statistical decompositions developed by [Firpo, Fortin, and Lemieux \(2014\)](#) are a flexible accounting device, helpful in determining whether observable characteristics of workers and occupations can account for changes in the earnings distribution. Nevertheless, it has some limitations. One is that the residual in the wage equation contains the contribution to wages of workers' sorting optimally across occupations. A second limitation resides in the interpretation of the decomposition in the face of general equilibrium adjustments. As noted by [Firpo, Fortin, and Lemieux \(2014\)](#), in response to a shock to the task demands, worker mobility across occupations will tend to limit changes in occupation prices, and this approach will attribute wage variation to changes in the returns to skills. Our [Section 5.2](#) model is designed to grapple both with occupational sorting and general equilibrium effects. The model does, however, impose parametric assumptions on workers' idiosyncratic ability to work in each potential occupation. Despite their differences, both approaches demonstrate that changes in occupations' task content generate a large fraction of the increase in 90-10 earnings inequality observed between 1960 and 2000.

5.1 Decompositions Using RIF Regressions

In this section, we perform a statistical decomposition introduced by [Fortin, Lemieux, and Firpo \(2011\)](#) to assess the role of occupations’ task content on earnings inequality. Fortin, Lemieux, and Firpo introduce a method with which to decompose changes in the distribution of earnings across points in time on the basis of worker and occupational attributes. This method, which can be thought of as an extension of a Oaxaca-Blinder decomposition, breaks down changes over time in any quantile of the earnings distribution into the contribution of observable changes in worker and occupational characteristics (the “composition” effect) and the contribution of implicit changes in the rewards to those characteristics (the “wage structure” effect). One can further break down the composition and wage structure effects into the parts belonging to each of these characteristics (e.g., worker’s educational attainment, occupational task content, etc.).

The basis of the decomposition is the following specification of workers’ earnings as a function of their observed characteristics and the tasks of the occupations in which they work:

$$\log W_{ijt} = \log \pi_{0t} + \sum_{h=1}^H T_{hjt} \log \pi_{ht} + \sum_{k=1}^K \alpha_k \tilde{S}_{kg} + \log \epsilon_{ijt}. \quad (2)$$

In this equation, i is an individual, W_{ijt} is the individual’s wage, and \tilde{S}_{gk} is an observable skill characteristic k for an individual who is in group g . And, $\log \pi_{ht}$ is a regression coefficient that represents the log price of task h in period t .

To perform our decompositions, we compute recentered-influence-function (RIF) regressions that describe, for workers in each quantile, the relationship between real log earnings and different occupational and worker characteristics. In these RIF regressions, the coefficient estimates will vary by quantile; coefficient estimates for the 10th and 90th percentiles are given in Appendix E.1. The worker characteristics include a race indicator and an indicator for marital status, along with education and potential experience categorical variables.²⁴

Our occupational characteristics are the measures based on [Spitz-Oener \(2006\)](#) and [Firpo, Fortin, and Lemieux \(2014\)](#) that we have discussed in Section 2.3. Since the different task measures (e.g., routine cognitive versus nonroutine interactive) are scaled differently — not

²⁴White individuals belong to the omitted race category. Married individuals belong to the omitted marital status category. The education categories are Some High School; High School; Some College (which is the omitted group); College; and Post-graduate. The potential experience categories are defined by ten-year intervals (with individuals with 20 to 29 years of potential experience belonging to the omitted group.) These education and potential experience categories are more coarsely defined than in [Firpo, Fortin, and Lemieux \(2014\)](#). We adopt this classification to be consistent with our analysis in Section 5.2.

The sample includes only males. We make this restriction since the RIF regression decompositions are ill-equipped to handle the large increase in female labor force participation observed in the first half of our sample period. Appendix E.2 presents our decompositions for samples that include female workers. When females are included in the sample, the (unexplained) “wage structure” effects of our task measures are considerably larger in the 1960s, but similar in other decades. The composition effects are also similar to what we report here.

only because employers tend to systematically mention some types of words more frequently than others, but also because our algorithm may be better at detecting certain types of words than others — it is necessary to standardize our task measures. We normalize $T_{hjt} \equiv (\tilde{T}_{hjt} - \mu_h) / \sigma_h$; here μ_h is the mean and σ_h is the standard deviation of keyword frequencies for task group h across years and occupations. Standardizing variables this way eliminates permanent cross task variation in mentions but, since we apply this same normalization across all occupations and years, retains the ability to do comparisons both across occupations at a point in time and within occupations across time. We emphasize that our normalization does not eliminate between-occupation variation in task content.

Decompositions Using Spitz-Oener’s (2006) Classification

We begin by grouping tasks into nonroutine analytic, nonroutine interactive, nonroutine manual, routine cognitive, and routine manual categories. We highlight the importance of our time-varying occupational measures by employing two sets of decompositions. The first decomposition is based on a new measure, $T_{hj.} \equiv \sum_{t=1960}^{2000} \frac{\vartheta_{jt}}{\sum_{t'} \vartheta_{jt'}} T_{hjt}$, emulating previous analyses, like [Firpo, Fortin, and Lemieux \(2014\)](#), in which task measures are fixed over time for a given occupation.²⁵ In the second decomposition, T_{hjt} is allowed to freely vary across time within occupations.

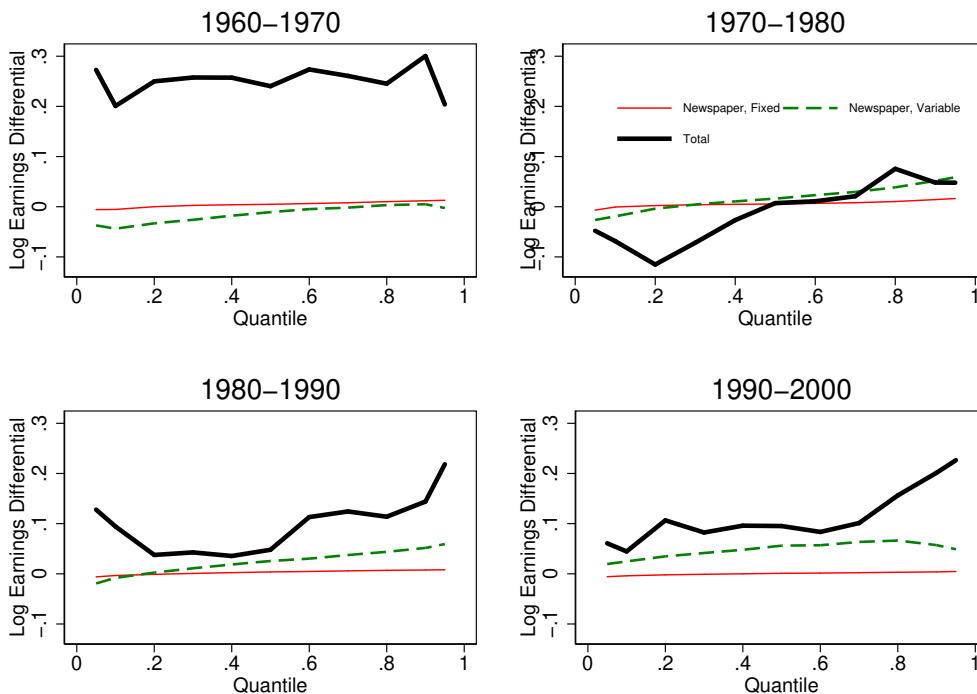
Figure 4 presents our decompositions, together with the total change at each percentile of the distribution, for each decade between 1960 and 2000. The thick solid line shows total observed changes for each percentile. According to the top-left panel, average earnings increased between 1960 and 1970, with little change in earnings inequality. In the following decades, from 1970 to 2000, inequality increased more sharply, while average earnings increased less. To what extent can occupational characteristics account for these changes?

We plot the contribution of occupational task content, via composition effects, in the dashed and thin solid lines in Figure 4. The thin solid line — computed using task measures that are fixed throughout the sample — accounts for a small part of the changes in the earnings distribution. According to this measure, occupational characteristics account for a 2 log point increase in 90-10 inequality between 1960 and 1970 and a 1 log point increase in each of the next three decades.

By contrast, when we allow task measures to vary across time, occupational characteristics account for a substantial increase in 90-10 inequality. Between 1960 and 2000, with our preferred, time-varying measure of tasks, occupational changes can account for a large increase in male earnings 90-10 inequality: 5 log points in the 1960s, 7 log points in the 1970s, 6 log points between 1980 and 1990, and 3 log points between 1990 and 2000.

²⁵Whether $T_{hj.}$ is computed using the occupation’s sample mean over the five decades or is taken from a single year is immaterial for our results below. What matters is that the measures are time invariant for a given occupation-task combination.

Figure 4: Decomposition of Real Log Earnings

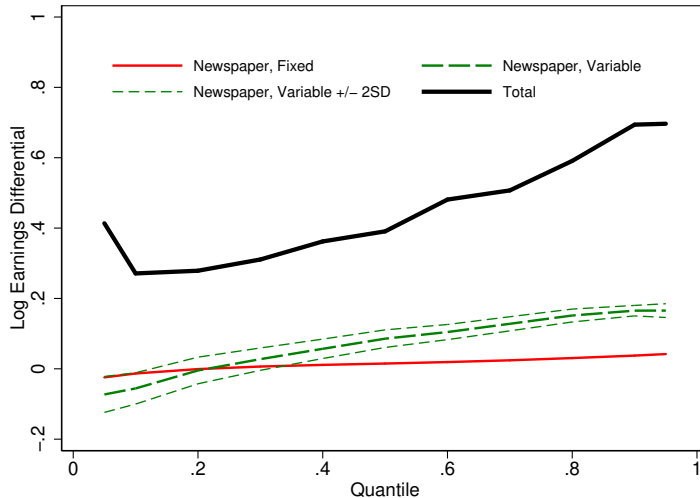


Notes: The thick solid line presents changes in log earnings of workers at different quantiles of the distribution. The thin solid line and the dashed line give the contribution of task changes (via the composition effects) using two different measures of occupational characteristics.

Wage structure effects — reflecting changes in the RIF regression coefficients associated with our task measures — account for a modest decline in inequality over our sample period, 1 log point when using the task measures that vary across time, and 4 log points when using the task measures that are fixed over the sample period. We choose to relegate plots of these wage structure effects to an appendix, since these wage structure effects are sensitive to the choice of the omitted value of the task measures. This issue pervades decompositions which build on the Oaxaca-Blinder decomposition, including the [Fortin, Lemieux, and Firpo \(2011\)](#) decomposition which we are employing. However, for the sake of completeness, we report all of the wage structure effects associated with our decompositions in Appendix [E.2](#).

In Figure [5](#), we sum up the decompositions in the four panels of Figure 4. Over these four decades, the 90-10 ratio of earnings increased by 42 log points among male workers. (Throughout the remainder to the section, reported inequality changes pertain to the 1960 to 2000 period unless otherwise specified.) Of this change in earnings inequality, our measures of occupational changes account — via composition effects — for a 22 log point increase. In this figure, we also plot the two standard error confidence interval of these composition ef-

Figure 5: Decomposition of Real Log Earnings



Notes: The thick solid line presents changes in log earnings of workers at different quantiles of the distribution. The thin solid line and dashed lines give the contribution of occupations through compositional changes, using two different measures of occupational characteristics.

fects. The two standard error confidence interval for the increase in 90-10 earnings inequality that is due to our task measures spans 18 to 27 log points.²⁶ On the other hand, occupational characteristics account for a more modest, but still important, 5 log point increase in 90-10 earnings inequality when using measures which are fixed within occupations throughout the sample period. We conclude that variation in task content that includes changes within occupations across time can account for a large fraction of the rise in inequality. The contribution of occupational changes coming only from differences in task content between occupations is comparatively smaller.

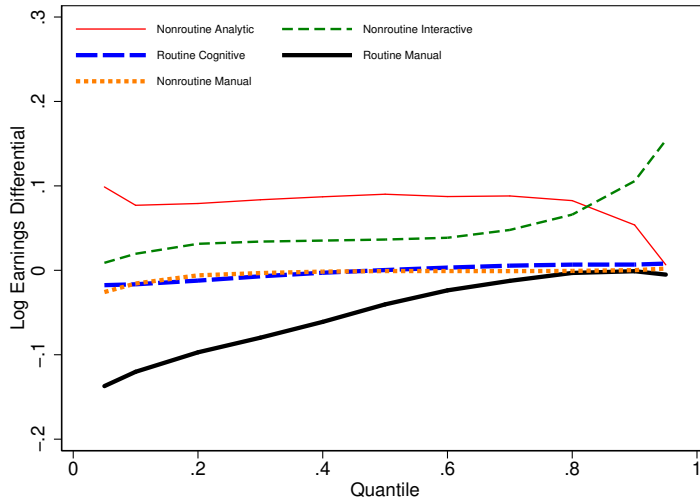
In sum, given the large changes in workers' activities within occupations that we uncovered in the previous section, decompositions which rely only on between-occupation changes in task or skill-intensity understate the contribution of composition effects on changes in the earnings distribution.²⁷

In Figure 6, we present the composition effects, broken down by task. The key result from this exercise is that, among the estimated compositional effects, changes in routine manual

²⁶These confidence intervals aim to measure the uncertainty surrounding our sampling of newspaper text. We construct 20 bootstrapped samples from our newspaper text. For each of these bootstrapped samples, we re-estimate our RIF regression based decompositions. To construct the dashed lines in Figure 5, we compute the standard deviation at each quantile of the RIF regression estimated contribution of our task measures to changes in the earnings distribution.

²⁷There are analogous wage structure and composition effects for the demographic, experience, and education variables. We do not plot these here. Throughout the entire distribution, but especially across the right tail of the distribution, the composition effect for education is positive, indicating that increases in male workers' educational status is associated with higher earnings and earnings income inequality. These results are consistent with those of [Firpo, Fortin, and Lemieux \(2014\)](#).

Figure 6: Detailed Decompositions of Real Log Earnings

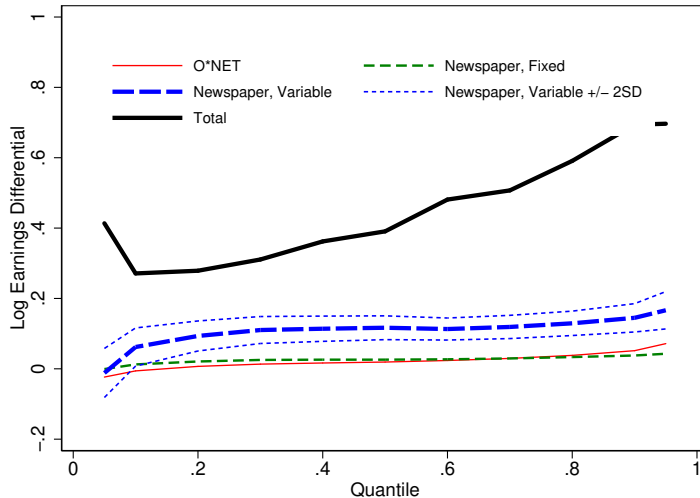


Notes: The figure describes the contribution of individual occupational characteristics, through compositional changes, to changes in the earnings distribution. We use the newspaper-based task measures which are allowed to vary within occupations across time.

and nonroutine interactive tasks generate the largest changes in labor income inequality. These composition effects are due to a combination of i) a large decline in economy-wide routine manual and cognitive task content and a corresponding increase in nonroutine interactive and analytic task content; ii) a stronger association between workers' earnings and their occupations' tasks (a larger estimated $\log \pi$) for routine manual tasks at the bottom of the distribution than in the top; and iii) a stronger association between earnings and nonroutine interactive task content at the top of the distribution than at the bottom.

The U.S. economy experienced several consequential changes since 1960, including dramatic technological progress and an increasing openness to trade. These developments have induced a shift in the composition of tasks that workers perform, and has re-shaped returns to these tasks. Our results suggest that changes in the task content of occupations translated shocks to trade and technology into widening inequality. Changes in the task returns played a more modest role. The implication is that, relative to the top of the distribution, the tasks which declined in importance over the sample period (routine manual tasks) were highly priced at the bottom of the wage distribution. Concurrently, tasks priced relatively highly for high-wage jobs (nonroutine interactive tasks) increased in importance between 1960 and 2000. A second implication follows from a comparison of the decompositions based on fixed and time-varying task content measures. With fixed task content, shifts in the tasks performed by workers can only arise via changes in the prevalence of occupations at different points of the distribution. Our decompositions indicate that such between-occupation shifts were less important in accounting for widening inequality, relative to the large within-occupation

Figure 7: Decomposition of Real Log Earnings



Notes: The figure describes the contribution of occupational characteristics through compositional changes, using [Firpo, Fortin, and Lemieux \(2014\)](#)’s task definitions.

changes in task content that we have documented.

Decompositions Using [Firpo, Fortin, and Lemieux \(2014\)](#)’s Classification

We now perform a similar set of decompositions using [Firpo, Fortin, and Lemieux \(2014\)](#)’s task classification. Figure 7, analogous to Figure 5, plots the composition effects of our technology and offshoring measures on the earnings distribution between 1960 and 2000. Here, these task measures account for a 8 log point increase in 90-10 inequality, with a 2-standard error confidence interval of 0.03 to 0.14. Using fixed-over-time occupational measures yields smaller results. Note that because there is a direct mapping between [Firpo, Fortin, and Lemieux \(2014\)](#)’s classifications and O*NET work activity measures, we can include measures based on O*NET. Results from decompositions based on our fixed-over-time newspaper task measures mirror those based on O*NET’s measures, confirming that our newspaper-based measures track similar task content as those based on O*NET.

Sensitivity Analysis

In the appendices, we consider three sets of exercises to examine the sensitivity of our results. First, in Appendix E.2, we examine the robustness of our benchmark results to changes in the way we construct mappings — from newspaper text to Spitz-Oener’s task groupings, to our transformation of the frequency of task-related words to T_{hjt} (ranking occupation-year observations by their task content instead of applying the normalization applied in page 22),

and, finally, to the inclusion of women in the sample.²⁸ Second, given the current discordance between the regions of the United States from which we are characterizing occupational characteristics (New York and Boston) and the regions we use to measure workers’ income and demographic variables are measured (the entire U.S.), we re-compute Figures 5 through 7 using only census data from the New York and Boston MSAs (see Appendix E.3). Third, in Appendix E.4, we apply hourly wage data from the CPS Merged Outgoing Rotation Group, instead of annual labor income data from the decennial census, to analyze changes in income inequality.²⁹ These three different samples present a consistent depiction on the relationships between our job characteristics and trends in labor income inequality.

5.2 Decompositions in an Estimated Equilibrium Model

In this section we take an alternative approach to calculating changes in the earnings distribution. We begin with a quantitative model in which workers sort based on comparative advantage, along the lines of [Burstein, Morales, and Vogel \(2015\)](#). We consider the effect of changes in the parameters of occupations’ production functions, and interpret these changes as reflecting exogenous shifts in the demand for worker-produced tasks.

We consider a closed economy with many time periods $t = 1, 2, \dots$ and a continuum of workers. Each individual worker i belongs to one of a finite number of groups, indexed by $g = 1, \dots, G$. The mass of workers in group g is L_{gt} . Workers of type g are endowed with a set of skills S_{gh} , $h = 1, \dots, H$, where h indexes tasks that workers perform in their occupations. Worker i produces task h by combining skills and time: $q_{iht} = S_{gh} \cdot l_{iht}$. Here, l_{iht} equals the amount of time the worker allocates to task h . Each worker has a total of one unit of time, which she supplies inelastically in one of $j = 1, \dots, J$ occupations.

Worker i , if she works in occupation j , produces

$$V_{ijt} = \epsilon_{ijt} \prod_{h=1}^H \left(\frac{q_{iht}}{T_{hjt}} \right)^{T_{hjt}} \quad (3)$$

units of output. In Equation 3, ϵ_{ijt} is an occupation-worker unobserved efficiency level, and T_{hjt} gives the importance of task h in occupation j . We fix $\sum_h T_{hjt} = 1$ for each occupation and time period.³⁰ Variation in T_{hjt} across occupations captures, for example,

²⁸In an unreported robustness check, we also consider an alternate specification in which task measures are broken out categorically, into quartiles. While the estimated composition effects are robust to the alternate specification, as well the omitted task quartile, the wage structure effects are not. The sensitivity of wage structure effects to the omitted group, however, is a common issue in Oaxaca-Blinder-type decompositions.

²⁹We acknowledge a trade-off here: While we would prefer to use hourly wages as the basis for our measurement of income inequality, we wish to take advantage of the longer sample which the decennial census offers.

³⁰Throughout the model and its estimation, we adopt the stance that the five Spitz-Oener task categories proxy for the full set of mutually exclusive occupational tasks. A potentially omitted sixth task category would affect the estimation and results insofar as they represent a large share of worker time, and are orthogonal to — in their trends and skill requirements — those in the observed task groups.

that some occupations are more intensive in routine analytic tasks than others. To match our time-varying measures of task content, we allow the parameters T_{hjt} to evolve exogenously through time. Such changes could reflect, again as an example, declines in the demand for worker-performed routine manual or routine cognitive tasks caused by a decline in the price of computers, or increases in nonroutine interactive tasks related to the increased importance of team management.

We assume that worker i 's wages, W_{ijt} , equal the value of the output she produces, $P_{jt}V_{ijt}$, which represents the product of the output produced and the price of the occupation j specific output. Taking P_{jt} as given, each worker chooses the amount of time spent on each of the H tasks to maximize the value of her output. The solution to this problem implies that $l_{ijt} = T_{hjt} \cdot \left(\sum_{h'=1}^H T_{h'jt} \right)^{-1} = T_{hjt}$.³¹

Plugging the optimal time allocation back into Equation 3 yields worker i 's log wages

$$\log W_{ijt} = \log P_{jt} + \sum_{h=1}^H T_{hjt} \log S_{gh} + \log \epsilon_{ijt}. \quad (4)$$

We assume that workers are freely able to choose their occupations to maximize their wages. Workers take as given each occupation-specific output price, and the task activities associated with each occupation. The idiosyncratic component of worker i 's returns from working in occupation j , ϵ , is a Frechet-distributed random variable, drawn independently across occupations and workers, with shape parameter θ , i.e., $\Pr[\epsilon_{ijt} < z] = \exp(-z^{-\theta})$. The parameter θ is an inverse measure of the dispersion of ϵ_{ijt} within group-occupation pairs.³²

The Frechet formulation conveniently generates expressions for the fraction of group g workers who work in occupation j and the average wage of group g workers. The probability that a worker of type g sorts into occupation j is

$$\lambda_{gjt} = \frac{\left(P_{jt} \prod_{h=1}^H (S_{gh})^{T_{hjt}} \right)^\theta}{\sum_{j'} \left(P_{j't} \prod_{h=1}^H (S_{gh})^{T_{hj't}} \right)^\theta}. \quad (5)$$

³¹Due to the assumption that the production function of occupation- j specific output is Cobb-Douglas, individual abilities do not shape the time spent in each task, although they will affect occupational choice.

³²In Appendix F, we outline the extra assumptions necessary to derive from Equation 2, the basis of our statistical decompositions, from Equation 4. Through the lens of our model, the coefficients on observable worker attributes in the RIF regressions encapsulate i) the attributes' contribution to task-specific skills and ii) the content of each task in an occupation. On the other hand, in the model task prices' (tasks' marginal contribution to occupational output) do not contribute to inequality once the occupation price is accounted for. The RIF regressions, however, are more flexible, as they accommodate within-occupation variation in task prices.

Moreover, the average wages of group g workers equal

$$\bar{W}_{gt} = \Gamma \left(1 - \frac{1}{\theta} \right) \cdot \left(\sum_{j=1}^J \left(P_{jt} \prod_{h=1}^H (S_{gh})^{T_{hjt}} \right)^\theta \right)^{1/\theta}, \quad (6)$$

where $\Gamma(\cdot)$ is the Gamma function.

To close the model, we assume that there is a representative consumer who has CES preferences over the output produced by the different occupations:

$$V_t = \left[\sum_{j=1}^J (\xi_j)^{\frac{1}{\rho}} \cdot (V_{jt})^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho-1}{\rho}},$$

with V_{jt} representing the sum of the output of individual workers, i , who produce occupation j output. Here, ξ_j parameterizes the consumer's preferences for occupation j output, and ρ gives the preference elasticity of substitution across occupations' output. Given these preferences, we can write the market-clearing condition for occupation j output, equating expenditures on the occupation's output to the wage bill of workers who are employed in occupation j :

$$\underbrace{\frac{\xi_j \cdot (P_{jt})^{1-\rho}}{\sum_{j'=1}^J \xi_{j'} (P_{j't})^{1-\rho}}}_{(A)} \underbrace{\sum_{g=1}^G \bar{W}_{gt} L_{gt}}_{(B)} = \sum_{g=1}^G \underbrace{\Gamma \left(1 - \frac{1}{\theta} \right) \left(\sum_{j'=1}^J \left(P_{j't} \prod_{h=1}^H (S_{gh})^{T_{hj't}} \right)^\theta \right)^{1/\theta}}_{(C)} \underbrace{\lambda_{gjt} L_{gt}}_{(D)}. \quad (7)$$

The left-hand side of Equation 7 contains two terms: the share of total expenditures on occupation j output (term A), multiplied by total expenditures (term B). On the right-hand side, the total wage bill of workers in occupation j is computed as the sum of the wage bill of group g workers in occupation j ; which in turn equals the product of the average wage of group g workers (term C) and the number of group workers (term D).

An equilibrium of our economy is the solution to $\{\lambda_{ij}\}$ and $\{P_j\}$, as determined by Equations 5 and 7.

With this model, we evaluate the impact of change in the demand for tasks on the equilibrium wage distribution. To do so, we first use data from a single period (1960) in combination with Equations 5 and 6 to estimate demographic groups' skills in producing tasks. Then, with our measures of changes in occupations' task content, we compute the counterfactual change in the distribution of wages, between 1960 and 2000, that is due only to changes in the demand for tasks. Appendix F details the equilibrium of the model, and delineates our algorithm to recompute the equilibrium in response to changes in the T s.

Throughout the remainder of the section, we fix $\theta = \rho = 1.78$, following [Burstein, Morales, and Vogel \(2015\)](#).

In estimating our model, we need to map task-related keyword frequencies, as observed in the newspaper data (\tilde{T}_{hjt}), to our production function parameters (T_{hjt}). To ensure that our production function parameters sum to one for each occupation-year, we apply the following transformation: $T_{hjt} = \tilde{T}_{hjt} \cdot \left(\sum_{h'} \tilde{T}_{h'jt}\right)^{-1}$.

Estimation of Task-related Skills

For each task h , we parameterize the relationship between skills and educational and demographic observable variables as follows:

$$\log S_{gh} = a_{h,gender} \cdot D_{gender,g} + a_{h,edu} \cdot D_{edu,g} + a_{h,exp} \cdot D_{exp,g}. \quad (8)$$

Here, $D_{gender,g}$, $D_{edu,g}$, and $D_{exp,g}$ are dummies for gender, education, and experience, which define the categories g . We estimate these a parameters via a method of moments procedure.³³

Our estimation recovers $a_{h,gender}$, $a_{h,edu}$, and $a_{h,exp}$ to minimize:

$$\sum_{g=1}^G \sum_{j=1}^J \omega_{gj}^\lambda \left(\log \lambda_{gj,1960} - \log \lambda_{gj,1960}^{\text{data}}\right)^2 + \sum_{g=1}^G \omega_g^W \left(\log \bar{W}_{g,1960} - \log \bar{W}_{g,1960}^{\text{data}}\right)^2. \quad (9)$$

In Equation 9, $\lambda_{gj,1960}^{\text{data}}$ and $\log \bar{W}_{g,1960}^{\text{data}}$ refer to the observed occupational shares and average wages.³⁴ The ω_{gj}^λ and ω_g^W are weights, characterizing the relative importance of each moment in our estimation. We compute these weights as the inverse of the variance of the moment across 40 bootstrapped samples, re-sampling separately from the decennial census (to recover uncertainty on workers' earnings and occupational choices) and from the newspaper text (to recover uncertainty on occupations' task measures).

Table 4 reports our estimates of groups' ability to perform each task. These estimates of comparative advantage are identified primarily from worker groups' sorting across occupations. For example, relative to other groups, workers with higher educational attainment tend to have a comparative advantage in occupations that are relatively intensive in non-routine analytic tasks; high school graduates and workers with some college tend to have a comparative advantage in occupations intensive in routine cognitive tasks; and high school dropouts have an advantage in occupations intensive in routine and nonroutine manual tasks.

³³As in the previous subsection, we have two gender, five educational, and four experience groups, with “male” as the omitted gender category, “Some College” as the omitted educational category, and 20-29 years as the omitted experience category.

³⁴Our estimation relies on data from 3240 (=40·81) moments—representing information from 40 groups (2 genders, 5 educational categories, and 4 experience categories) and 81 occupations—to identify 121 parameters: 81 occupation-fixed effects plus 40 a coefficients.

These estimates also imply that groups have a comparative advantage over tasks but, since tasks are bundled, ultimately what matters for earnings is the contribution of each task — measured by T_{hj} — to occupational output.³⁵

Table 4: Estimates of Skills

	Nonroutine Analytic	Nonroutine Interactive	Nonroutine Manual	Routine Cognitive	Routine Manual
Gender					
Female	-1.708 (0.117)	-0.299 (0.083)	-0.658 (0.595)	3.209 (0.210)	-3.800 (0.850)
Education					
< HS	-2.159 (0.158)	-0.494 (0.070)	4.194 (0.431)	-1.558 (0.132)	3.884 (0.543)
High School	-1.092 (0.057)	-0.368 (0.034)	2.413 (0.229)	0.322 (0.044)	1.943 (0.348)
College	1.449 (0.103)	0.372 (0.060)	-3.172 (0.939)	-1.369 (0.141)	0.750 (1.432)
Post-Graduate	1.285 (0.174)	0.290 (0.117)	-4.274 (1.556)	-1.504 (0.445)	5.006 (1.663)
Experience					
0-9 Years	-0.299 (0.066)	-0.859 (0.034)	1.312 (0.243)	0.714 (0.074)	-3.078 (0.284)
10-19 Years	-0.006 (0.022)	-0.209 (0.014)	0.409 (0.072)	0.273 (0.021)	-0.800 (0.087)
30+ Years	-0.076 (0.032)	0.045 (0.019)	0.416 (0.101)	0.239 (0.032)	-0.851 (0.134)

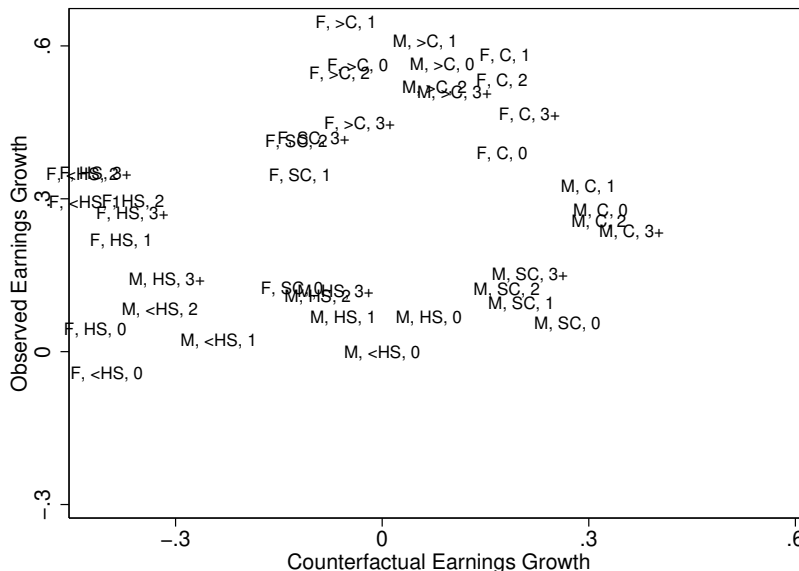
Notes: To compute the standard errors, we re-sampled 40 times from the 1960 decennial census to recover sampling uncertainty on earnings and occupational choices, and re-sampled 40 times from our newspaper text to recover sampling uncertainty on occupations’ task measures. For each bootstrapped sample, we recomputed the empirical occupational shares and group wages and then found the combination of parameters that minimized Equation 9. The omitted demographic groups are males, workers with Some College, and workers with 20-29 years of potential experience.

³⁵More specifically, focusing on the observable component of comparative advantage, group g will have a comparative advantage in occupation j , relative to group g' and occupation j' , if

$$\sum_{h=1}^H (T_{hj} - T_{hj'}) (\log S_{gh} - \log S_{g'h}) > 0.$$

For instance, consider comparing groups’ comparative advantage across three occupations: Physical Scientists (SOC=1920, an occupation intensive in nonroutine analytic tasks), Financial Clerks (SOC=4330, an occupation intensive in routine cognitive tasks), and Material Movers (SOC=5370, intensive in routine manual and nonroutine manual tasks). The T vectors associated with these three occupations are (with tasks ordered alphabetically): (0.73, 0.18, 0.03, 0.04, 0.02), (0.14, 0.29, 0.02, 0.52, 0.04), and (0.25, 0.49, 0.10, 0.07, 0.09). Based on these task measures in conjunction with the formula above, we would conclude that college graduates have a comparative advantage relative to all other education groups in the Physical Scientist occupation, high school graduates have a comparative advantage in the Financial Clerks occupation, and workers with less than high school education have a comparative advantage in the Material Movers occupation.

Figure 8: Counterfactual and Observed Earnings Growth, 1960-2000, By Demographic Group



Notes: Each point gives the growth in wages for one of the 40 g groups. The first character—“M” or “F”—describes the gender; the second set of characters—“<HS,” “HS,” “SC,” “C,” or “>C”—the educational attainment; and the third set of characters the number of years — “0” for 0-9, “1” for 10-19, “2” for 20-29, “3+” for ≥ 30 — of potential experience for the demographic group.

With the aim of substantiating these estimates, we make two points. First, as an assessment in-sample fit of the model, we compare $\log \lambda_{gj,1960}$ and $\log \lambda_{gj,1960}^{\text{data}}$ (across the 3240 group-occupation observations), and $\log \bar{W}_{g,1960}$ and $\log \bar{W}_{g,1960}^{\text{data}}$ (across the 40 groups). The correlation between the model-estimated occupational shares and the observed shares is 0.65, while the correlation between $\log \bar{W}_{g,1960}$ and $\log \bar{W}_{g,1960}^{\text{data}}$, is 0.98. Second, identification of the parameters in Table 4 follows transparently from workers’ sorting patterns. Based on our set-up, the share of workers will be high for occupations in which their skills will be used intensively. For example, mirroring the estimates in Table 4, the correlation between the average number of words related to routine cognitive tasks in occupation j and an occupation-group’s $\log \lambda_{gj,1960}$ is substantially higher for women compared to men (0.32 versus -0.03); for high school graduates compared to post-graduates (0.24 versus -0.01); and for workers with fewer than 10 years of experience compared to workers with 30+ years of experience (0.15 versus 0.06).

Counterfactual Earnings Distribution

Having estimated the distribution of skills, we now compute the counterfactual dispersion in wages that would otherwise have been obtained in succeeding decades—in 1970, 1980, 1990, and 2000—as a result of changes in the demand for tasks over our sample period. To do so,

we consider an exogenous change in the T_{hjt} production function parameters (which, again, we measure through the changes in task-related keyword frequencies). Stemming from these changes in the demand for tasks, we compute the counterfactual equilibrium that would have obtained, fixing $\log S_{gh}$ to the values we estimated in the previous subsection, but allowing T_{hjt} to change over time.³⁶

Figure 8 plots the growth in \bar{W}_{gt} between 1960 and 2000, both as observed in the data and according to our counterfactual exercise. Wages increase most quickly for workers with college degrees or with post-graduate education. According to our estimated model, wage growth is fastest for high-education demographic groups because these groups have an advantage in nonroutine analytic and interactive tasks as of 1960, and the relative demand for these tasks has increased over the subsequent 40 years.

Increases in between-group inequality signify larger overall inequality. Figure 9 plots changes in 90-10 inequality, both the observed growth rate and the counterfactual growth rates that are due only to changes in T_{hjt} . Between 1960 and 2000, 90-10 inequality increased by 26 log points for the entire population, 38 log points for male workers, and 15 log points for female workers. According to our counterfactual exercises, within occupation changes in task demand account for much of the observed increase in 90-10 inequality: 23 log points for the entire sample, 15 log points for female workers, and 16 log points for male workers.

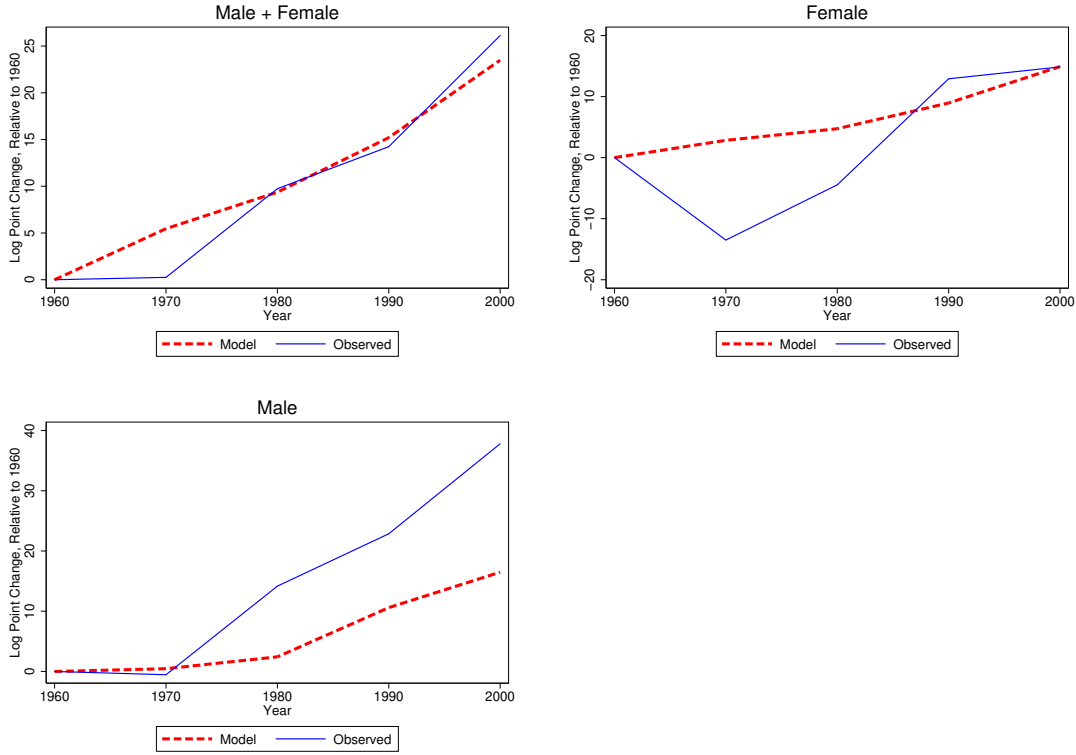
Discussion

Occupational choice and wage data from the beginning of our sample suggest that workers with certain demographic characteristics (e.g., workers with a college degree) have an advantage in the occupations rich in tasks which have happened to grow over the subsequent forty years. Since these demographic groups were already highly remunerated in 1960, changes in the demand for tasks have increased earnings inequality.

Where do these shifts in the demand for tasks come from? Our model omits capital as an input in the production of tasks. Likely, some of the differential growth rates of T_{hjt} across task groups reflect, at a more fundamental level, changes in capital prices. To the extent that the elasticity of substitution between workers and capital is relatively high in the production of routine tasks, a decline in the price of capital will be equivalent to a reduction in the demand for worker-performed routine tasks. Moreover, insofar as employers' innovation and technology adoption decisions are a function of the supply of workers of different skill types, changes in the T_{hjt} not only embody exogenous changes in the demand for tasks (which has been our interpretation here), but also reflect changes in the skill composition of labor supply. An interesting topic for future work would be to build on our model of occupations

³⁶In the exercises in this section, we also fix the sizes of the 40 demographic groups to their 1960 values. An alternate procedure would allow these labor supplies to vary throughout the sample according to observed demographic changes. This alternate procedure yields similarly large increases in 90-10 inequality in the counterfactual equilibrium, compared to those reported in Figure 9.

Figure 9: Counterfactual and Observed 90-10 Inequality, 1960-2000



Notes: Each panel plots the change in 90-10 earnings inequality, as observed in the decennial census (solid line), and are due only to changes in the demand for tasks (dashed line).

as a bundle of tasks, endogenizing changes in the T_{hjt} while acknowledging that workers and capital combine to perform each individual task and that innovations which lead to these declines in capital prices are potentially a response to the changing composition of the workforce.

The statistical decomposition in the previous section and the counterfactual exercise in this section, while markedly different in their approach and assumptions, result in comparable assessments of the role that task measures play in explaining increasing inequality. On the one hand, in contrast to the statistical decomposition, worker sorting plays a key role in the equilibrium model. Rewards to skills are occupation specific (and determined by the occupations' associated task content). Sorting amplifies the effect of observed changes in tasks on inequality.³⁷ Moreover, while heavily parameterized, the model takes into account the labor responses to changes in task prices induced by the shifts to the T_{hjt} . These general equilibrium effects also tend to generate more inequality explained by tasks in the model

³⁷In principle, sorting on unobservable characteristics could lead the statistical decomposition to either overstate or understate the role of tasks in accounting for increased inequality. If, over time, there is increased sorting of workers with high unobserved ability into jobs at the top of the distribution, then the decomposition's wage structure effects will under-represent the contribution of task price changes to inequality. [Firpo, Fortin, and Lemieux \(2014\)](#) argue that this is likely the case. See their Section I.B.

relative to the statistical decomposition.

On the other hand, we only evaluate the effect of within-occupation changes in task demands in the model, while other shocks to fundamentals could also shape the income distribution. These other shocks include changes in the demand for occupations (measured by ξ_j in the model), and potentially represent a source of widening income inequality that is encapsulated by the statistical decompositions and not the counterfactual exercises. Moreover, to the extent that the price of individual tasks vary within occupations, the RIF regressions will capture a source of inequality that the model cannot.

6 Conclusion

In this paper, we chronicle the changes in the U.S. occupational structure between 1960 and 2000. We document that a predominant share of changes in the skill and task composition of the workforce has occurred within rather than between occupations. Not only is it the case that occupations intensive in routine tasks have declined as a share of the workforce — a central pattern of the existing task literature — but also individual occupations’ routine task content has declined as well.

We then demonstrate that within-occupation task changes are fundamentally important in an examination of the evolution of income inequality. We first perform a statistical decomposition on the earnings distribution and find that compositional changes associated with occupational characteristics can explain an 18 log point increase in labor income inequality (as measured by the 90-10 ratio) between 1960 and 2000. We then construct and estimate a Roy model in which changes in the demand for tasks determine workers’ comparative advantage. Our estimated model accords with the results from our statistical accounting exercise.

Beyond this project, our newspaper data have the potential to address other economic questions related to the labor market. For example, in related work we use the text to measure the adoption of new computer technologies, to study how these technologies interact with the task content of jobs. More generally, we view our newspaper-based job vacancy text as offering an opportunity to study questions that have been examined using online job vacancy text over a longer time horizon than previously possible.

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Online Appendix

A Additional Comparisons of the Newspaper Data to Existing Data Sources

Certain variables are present in both our new newspaper data and in previously available census and CPS data. With the aim of demonstrating the overall reliability of our newspaper data, we compare the frequency of different occupations, as well as educational characteristics for each occupation, across the two data sources. Unlike the comparisons that we made in Section 3, the occupational measures potentially vary across time in the data set to which we are comparing our newspaper data.

First, Figures 10 and 11 depict the share of workers (in the decennial census) in different occupational groups, along with the frequency of job ads in the same groups. Figure 10 presents this relationship at the 2-digit level. In 1960, 1980, and 2000, the correlations between census job frequencies and frequencies in our newspaper job ads are 0.57, 0.76, and 0.66, respectively. Our newspaper data set over-represents the Sales, Health Practitioner, and Architecture/Engineering occupational groups, and conversely under-represents the Transportation, Production, and Installation and Maintenance occupational groups. (Hershbein and Kahn, 2016’s data set of online job postings also exhibited a similar under-representation of blue-collar occupations.)³⁸ Figure 11 presents the same set of relationships, now using a 4-digit SOC classification. Here, the correlations among the two measures of occupational size are weaker, ranging between 0.14 in 1960 to 0.41 in 1980.

Second, we compare measured educational attainment of occupations’ workers in the decennial census to our vacancy postings’ stated education requirements. In the newspaper text, we search among a list of acronyms and words to identify an undergraduate degree as a requirement, and a second list of acronyms and words to identify a professional degree requirement.³⁹ In Figure 12, we compare the undergraduate attainment/requirements across 4-digit SOC codes, using a local polynomial smoother. Within the individual years that are plotted, the correlations between the two measures are 0.43, 0.58, 0.75, and 0.34. (The correlation for 1990, the unplotted year, is 0.57.)

In Figure 13, we perform the same exercise for professional and post-graduate degrees. Here, the extent to which our data align with educational attainment in the decennial census is substantially weaker. The correlation in the pooled sample of years and occupations is 0.19. For the individual years in our sample, the correlations across SOC codes are 0.15, 0.17,

³⁸While blue-collar workers are underrepresented in our newspaper data relative to their employment shares, we emphasize that our analysis of changes in occupations’ task content (or of economy-wide task content) is not affected by this under-representation, since we weight occupations’ by their employment shares.

³⁹These two lists are i) “bachelors,” “bachelor,” “ba,” “bsme,” “bs,” “bsche,” “bsce,” “bscs,” and “bsee” and ii) “cpa,” “masters,” “ma,” “mba,” and “phd.”

Figure 10: Occupation Shares

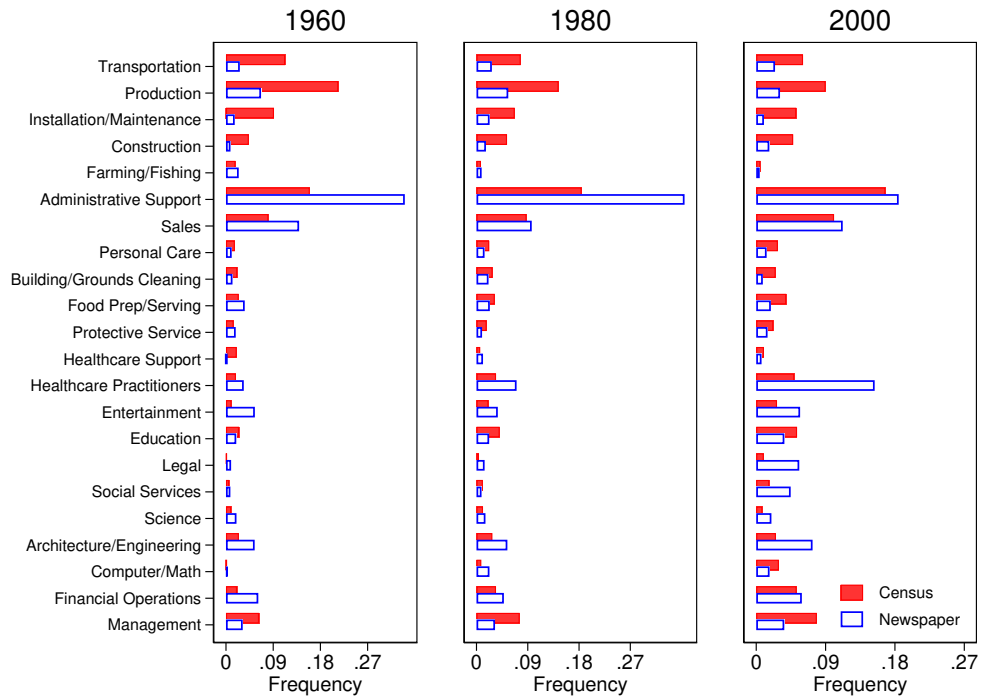


Figure 11: Occupation Shares

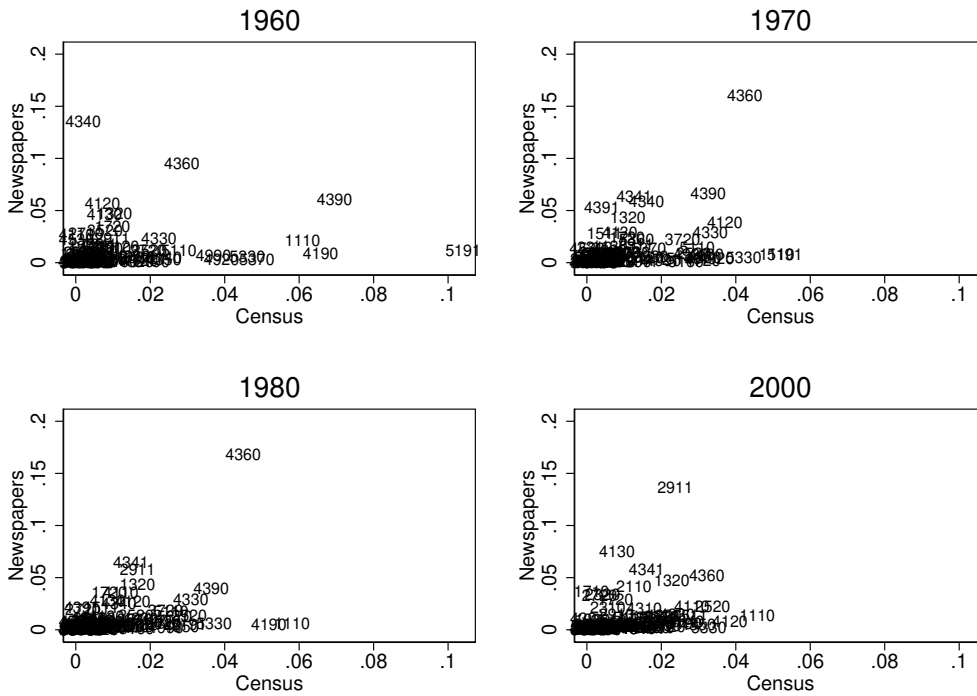
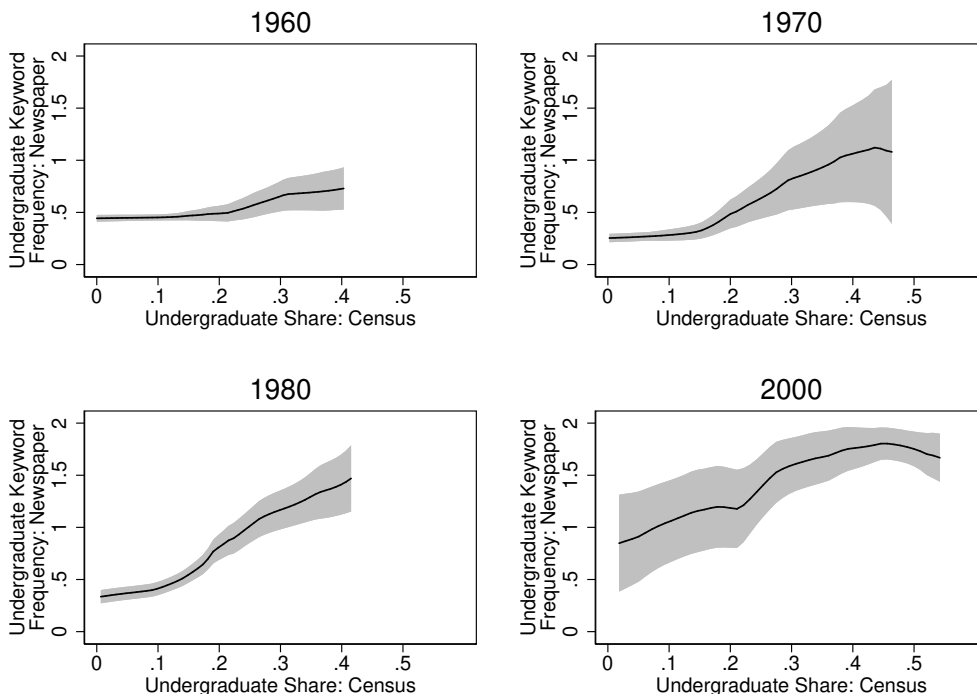


Figure 12: Educational Characteristics by Occupation



Notes: Each panel describes the relationship between the share of workers in each occupation with an undergraduate degree (according to the decennial census) on the x-axis; the fraction of newspaper ads which mention an undergraduate degree is on the y-axis. We apply a local polynomial smoother, weighting occupations by the number of ads in our newspaper data set in that year.

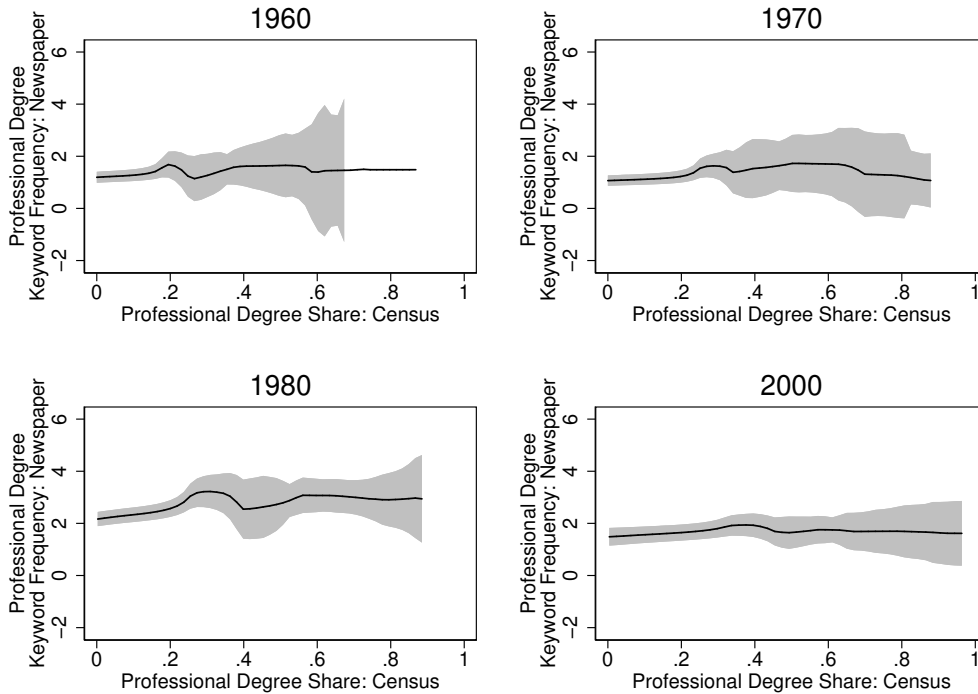
0.25, 0.29, and 0.11. Overall, we conclude that the undergraduate degree requirement data which we extract from our newspaper data are correlated with the more cleanly measured census data on workers' educational attainment, but only weakly so for professional and graduate degrees.

B Methods of Job Search

In this section we consider the possibility that the ads which appear in our data set represent a selected sample of all job search methods. In our main analysis, we observe a dramatic increase in words related to nonroutine tasks, which we interpret as reflecting the increasing importance of nonroutine tasks in the economy. But it is also plausible that employers posting vacancies for jobs requiring nonroutine tasks are increasingly likely to post in newspaper ads over time. This section provides empirical evidence that the representativeness of our data set (among the set of all channels of job search) has not changed within the sample period.

Here, we measure the methods that unemployed workers use to search for jobs. We can do this using the IPUMS CPS-ASEC (Ruggles, Genadek, Goeken, Grover, and Sobek, 2015).

Figure 13: Educational Characteristics by Occupation



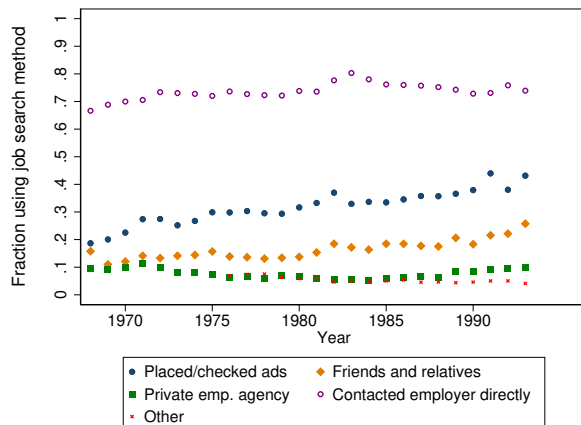
Notes: Each panel describes the relationship between the share of workers in each occupation with a graduate degree (according to the decennial census) on the x-axis; the fraction of newspaper ads which mention a graduate degree is on the y-axis. We apply a local polynomial smoother, weighting occupations by the number of ads in our newspaper data set in that year.

Unemployed workers are asked whether they have used particular job search methods, and are allowed to report as many methods as they like. The population analyzed here includes unemployed civilian workers, who are looking for a job, and who are between the ages of 16 and 64. Figure 14 reports the fraction of these workers who use alternative methods for finding a job. The variable of interest for our study is whether the unemployed worker “placed or answered ads” as a method of job search.

Figure 14 shows trends in the method of job search over time. Two methods, placing or answering ads and searching through friends and relatives, increase steadily from 1968 to 1993. Note that by themselves these upward trends are not necessarily problematic; what could pose a problem, however, is the presence of differential trends by occupation, educational background, or other demographic characteristics.

In what follows we consider whether there is selection into job search by task intensity of the worker’s prior occupation. If, for example, workers in occupations that are high in nonroutine tasks are more likely to search in newspapers over time, compared to workers in occupations low in nonroutine tasks, we would be concerned that selection is causing us to overstate the upward trend in nonroutine tasks.

Figure 14: Methods of Job Search Among Unemployed



Notes: The figure above reports the fraction of unemployed workers who use alternative methods for finding a job. Respondents are allowed to report as many methods as they deem appropriate; therefore the fraction using each method need not sum to 1.

To test this hypothesis, we first compute the mean task content in each occupation over the entire sample period. We then plot the fraction of workers searching for jobs through ads whose last occupation was highly intensive in, say, nonroutine interactive tasks (75th percentile or higher) and the same for workers in occupations that have a low intensity in the same task (25th percentile or lower).⁴⁰

Figure 15 plots the yearly averages for high versus low task intensity occupations. The main takeaway is that while the overall trend is increasing, there does not appear to be a differential trend by the task intensity of the worker’s prior occupation. This is reassuring for the main results of the paper because if, for example, the observed rise in interactive tasks were driven by selection of highly interactive job vacancies into newspapers, we would expect workers who work in highly interactive jobs to search more in newspapers over time, relative to workers in low interactive jobs.⁴¹

We test this hypothesis formally using the following regression:

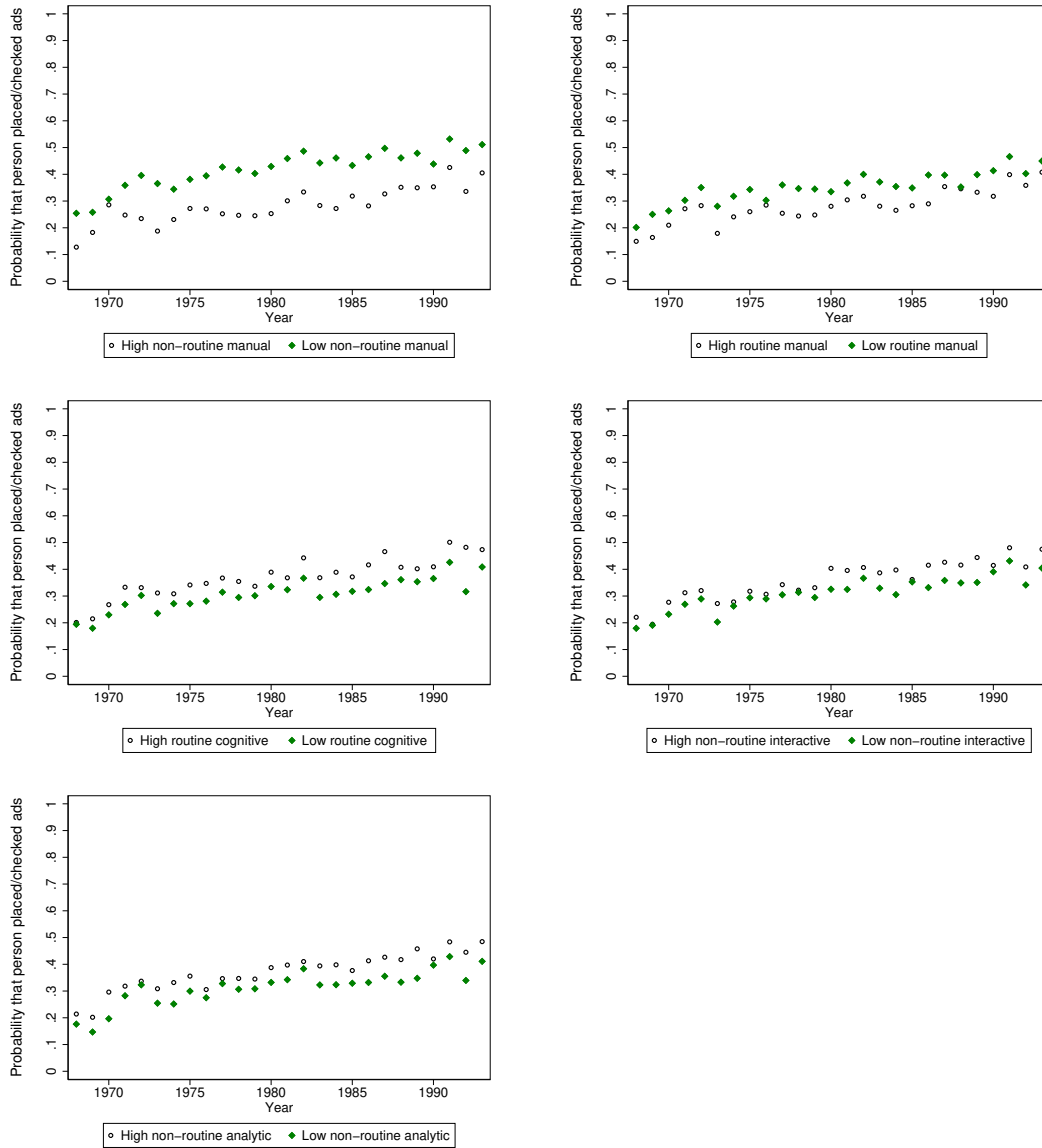
$$y_i = \beta_0 + \beta_i \tilde{T}_h^\tau + x_i' \gamma + \iota_t + \epsilon_i, \tag{10}$$

where \tilde{T}_h^τ is an indicator for being in the τ th percentile of the task h distribution (and h

⁴⁰The analysis that follows is not sensitive to this choice of threshold for high and low intensity occupations.

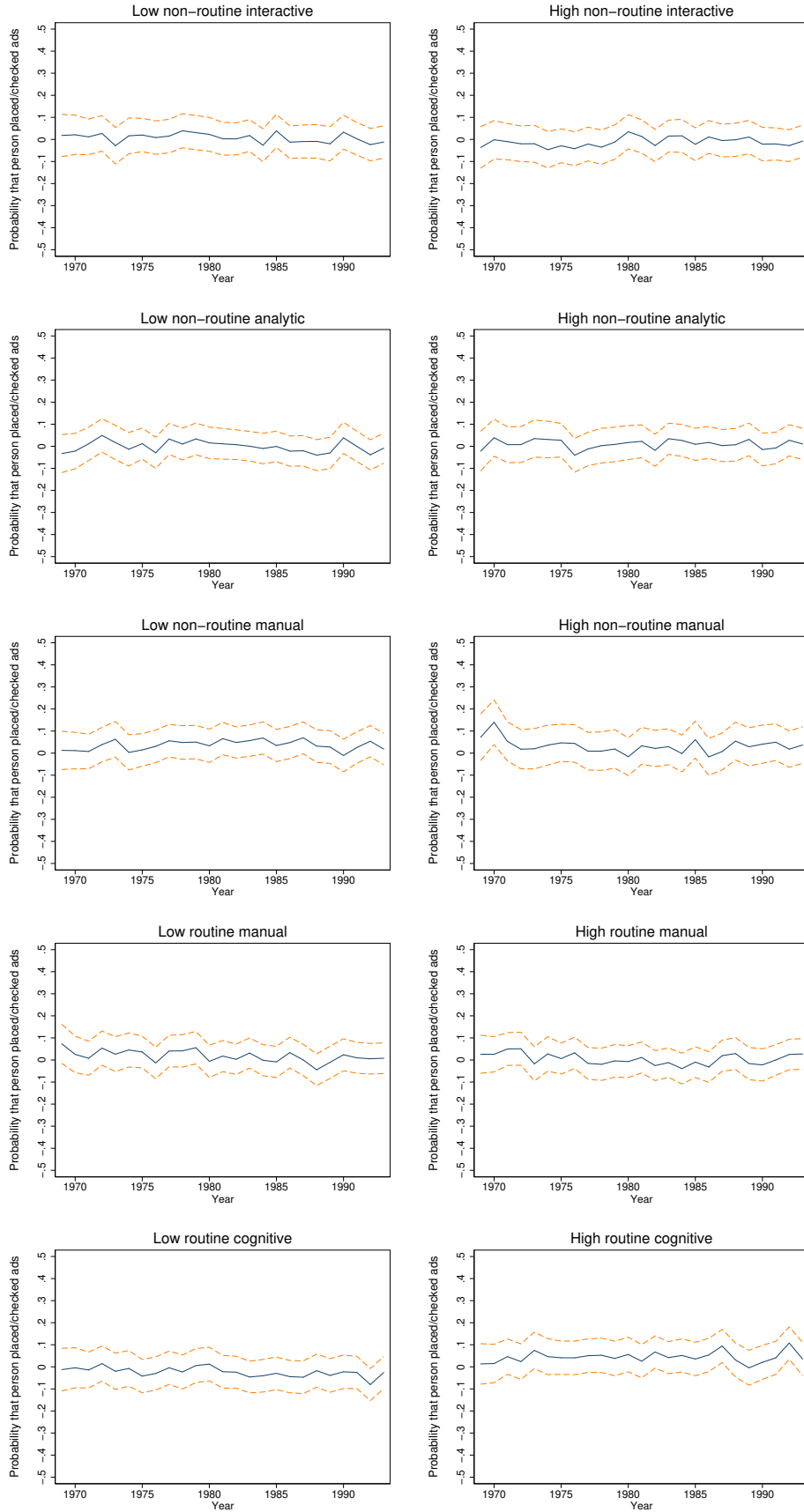
⁴¹While trends in job search do not appear to differ by occupation, there are *level* differences in job search: For example, workers in high routine cognitive occupations are more likely to use job ads as a search method compared with workers in low routine cognitive occupations. This pattern is consistent with our finding in Appendix A that job vacancies in administrative support occupations are more likely to appear in newspapers when compared to overall employment. That i) occupations with high routine cognitive task content are more likely to appear in newspapers, and ii) workers from these occupations are more likely to search in newspapers is reassuring for this validation exercise, since it demonstrates that demand-side differences in vacancy posting behavior are also reflected in supply side search behavior.

Figure 15: Trends in Job Search Method by Task Intensity of Occupation



Notes: The figure above plots the fraction of job seekers using job ads as a search method, by task intensity of prior occupation. “High” refers to being in an occupation in the 75th percentile or higher in a given task, while “low” refers to being in the 25th or lower percentile in a given task.

Figure 16: Trends in Job Search Method by Task Intensity of Occupation



Notes: The figure above plots the estimates for β_t in Equation 10 for each of the five tasks, along with the 95 percent confidence intervals. Each panel represents the results of a separate regression.

indicates one of the five Spitz-Oener task measures). In keeping with our regressions from Section 5.1, the vector x_i are controls including gender, marital status, experience dummies (<10 years, 10-19 years, 20-29 years, and 30+ years), a non-white race dummy, and dummy variables over our five educational groups. Figure 16 plots the estimates for β_t . The omitted year is 1968, so coefficients β_t are interpreted as relative to 1968. Overall, Figure 16 suggests no detectable trends in job search behavior through ads.

C Details on the Construction of the Database

This section provides further details that, due to space constraints, we could not include in Section 2. As discussed in that section, constructing the database entails transforming raw, unstructured text into a set of job ads for which we identify job titles and task contents. This requires four steps: i) identifying pages of job ads from the broader sample of advertisements, ii) processing the newspaper text files, iii) grouping occupations according to useful classifications, and iv) eliciting task and skill related information. We turn to each next. Note that some of the language in this appendix is taken directly from Section 2.

C.1 Details on the Latent Dirichlet Allocation Procedure, Used to Distinguish Vacancy Postings from Other Ads

Given the massive amount of newspaper text, it is practically impossible for us to manually distinguish job vacancy postings from other types of advertisements. A simple solution would be to remove newspaper pages where no job vacancy related words can be found. This solution, however, could be problematic as, for example, the word “sales” appears in vacancy postings for “sales representatives” and to advertise retail sales. Nevertheless, it is reasonable to assume that job vacancy postings would have different features (distributions of words, to be more precise) compared to other types of advertisements.

In our context, the Latent Dirichlet Allocation (LDA) model is used to distinguish pages of job ads (one of the model’s topics) from other groups of ads. Estimation of the LDA model denotes estimation of the probability that different sets of words (e.g., “experience,” “sale,” “price”) appear in different pages of advertisements, conditional on the topic of the ad. Since each page of advertisements contains a collection of words, the model will allow us to compute the probability that any one page of advertisements is comprised of job ads. Roughly put, the model identifies sets of words that frequently appear together in the same documents within a text corpus. For example, if there were only two types of ads in our newspaper data, job ads or sales ads, one set of ads would be characterized by containing the words “experience,” “years,” or “opportunity.” A second set of ads would be characterized by containing the words “store,” “save,” or “price.” Using this intuition, we apply LDA, an algorithm that categorizes documents within a corpus on the basis of their words. It is an

“unsupervised learning algorithm,” in the sense that a training data set is not required. The exposition in this section draws heavily from Blei et al. (2003, pp. 996-998).

Notation and Terminology

1. A *vocabulary*, V , is a set of all possible words.
2. A *word* w is a vector of length $|V|$. If w takes on the i th element of the vocabulary, then $w_i = 1$. Otherwise, $w_i = 0$.
3. A *document* is a sequence of N words denoted by $\mathbf{d} = (w_1, w_2 \dots w_N)$.
4. A *corpus* is a collection of M documents denoted by $\mathbf{D} = (\mathbf{d}_1, \mathbf{d}_2 \dots, \mathbf{d}_M)$.
5. A *topic* $z \in \{z_1, z_2, \dots, z_K\}$ denotes a “hidden label” across documents in a corpus. The dimensionality K is assumed to be known and fixed.

Data Generating Process

The model assumes the following process.

1. First, choose a vector $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_K)$ and a K by V matrix β . Hold these α and β fixed throughout the corpus.
2. Next, for each document \mathbf{d}_m in the corpus, choose a K -dimensional topic weight vector θ_m drawn from a Dirichlet distribution with parameter vector α . That is,

$$\Pr(\theta_{m1}, \theta_{m2}, \dots, \theta_{mK} | \alpha_1, \alpha_2, \dots, \alpha_K) = \frac{\Gamma\left(\sum_{k=1}^K \alpha_k\right)}{\prod_{k=1}^K \Gamma(\alpha_k)} \cdot \prod_{k=1}^K (\theta_{mk})^{\alpha_k - 1},$$

where each $\alpha_k > 0$ and $\Gamma(\cdot)$ refers to the Gamma function.

3. Finally, each word in a document \mathbf{d}_m is determined by first choosing a topic $z \in \{z_1, z_2, \dots, z_K\}$ where the probability of choosing a particular topic k is equal to $\Pr(z = z_k | \theta_{m1}, \theta_{m2}, \dots, \theta_{mK}) = \theta_{mk}$. Then, choose a word w_n from a word-topic probability matrix β where the n, k element of $\beta = \Pr(w_n = 1 | z_k = 1)$.

Conditional on α and β , the joint distribution of a topic mixture θ , a set of topics \mathbf{z} , and a document \mathbf{d}_m (which contains words w_n) is given by:

$$\Pr(\theta, \mathbf{z}, \mathbf{d}_m | \alpha, \beta) = p(\theta | \alpha) \prod_{n=1}^N p(z_n | \theta) p(w_n | z_n, \beta).$$

The marginal distribution, or likelihood, of a document \mathbf{d}_m which contains words w_n is given by integrating over θ and summing over potential topics z_k :

$$\begin{aligned} \Pr(\mathbf{d}_m|\alpha, \beta) &= \int p(\theta|\alpha) \left(\prod_{n=1}^N \sum_{k=1}^K p(z_k|\theta) p(w_n|z_k, \beta) \right) d\theta \\ &= \frac{\Gamma\left(\sum_{k=1}^K \alpha_k\right)}{\prod_{k=1}^K \Gamma(\alpha_k)} \cdot \int \prod_{k=1}^K (\theta_{mk})^{\alpha_k-1} \prod_{n=1}^N \sum_{k=1}^K \prod_{v=1}^V (\theta_{mk}\beta_{kv})^{w_n} d\theta. \end{aligned}$$

Estimation

The main purpose of LDA is to determine the distribution of the latent topics conditional on the observed words in each document. The distribution is as follows:

$$\Pr(\theta, \mathbf{z}|\mathbf{d}_m, \alpha, \beta) = \frac{\Pr(\theta, \mathbf{z}, \mathbf{d}_m|\alpha, \beta)}{\Pr(\mathbf{d}_m|\alpha, \beta)}.$$

The estimated values, $\hat{\alpha}$ and $\hat{\beta}$, are values of α and β which maximize the log likelihood of the documents:

$$\left(\hat{\alpha}, \hat{\beta}\right) = \arg \max \left\{ \sum_{m=1}^M \log [\Pr(\mathbf{d}_m|\alpha, \beta)] \right\}.$$

The posterior distribution cannot be computed directly. As a feasible approximation, we use Hoffman et al. (2010)’s Expectation Maximization algorithm. The python code for this algorithm is part of the *gensim* module; see Rehurek and Sojka (2010).

Details on Our Implementation

To construct our LDA model, we take samples of pages of 100 thousand pages of advertisements from each of our newspapers, separately: display ads in the *Boston Globe*, spanning 1960 to 1983; display ads in the *New York Times*, 1940 to 2000; classified ads in the *Boston Globe*, 1960 to 1983; classified ads in the *New York Times*, 1940 to 2000; and classified ads in the *Wall Street Journal*, 1940 to 1998. Since the text in display ads is larger, our code more easily identifies and processes the text in these ads. For this reason, we apply our processing code separately for these different types of ads.

For each of our five subsamples, we first restrict attention to pages of advertisements which are at least 200 words. From these pages of ads, we remove *stop words* (e.g., common words like “a,” “the,” and “and”), numerals, and words that are not contained in the English dictionary. We then *stem* words; that is, we remove word affixes so that words in different forms—singular nouns, plural nouns, verbs, adjectives, and adverbs—are grouped as one. To emphasize, the removal of certain types of words and the stemming of words pertains to

the construction of our LDA model. Once we have estimated this model, we will restore our original text.

After estimating the model, each page in each subsample is defined by a probability distribution over K topics. We pick the pages for which the probability of belonging to the topic with words common in vacancy postings is greater than 0.40. The choice of the cutoff balances a trade-off between throwing out too many vacancy postings (particularly job ads in sales-related occupations) and including too many non-job ads in our data set. Choosing a low cutoff will lead us to include pages of non-job-related ads at this stage. However, since succeeding stages will discard ads without job titles, these pages of non-job ads will be excluded.⁴²

LDA Results

In Table 5, we present partial results from our LDA procedure, listing the ten words which are most predictive of each topic for each of the subsamples in our sample: the *Boston Globe* classified ads, the *Boston Globe* display ads, the *New York Times* classified and display ads, and the *Wall Street Journal* classified ads. We chose the number of topics, K , so that i) there is a clear, identifiable topic associated with job ads, but ii) if we were to add a $K + 1^{\text{st}}$ topic, then there would be multiple job-related topics resulting from the LDA model. The words presented in these tables are those with the highest values of β_{nk} .

C.2 Processing the Newspaper Text Files

The goal of this step is to parse the raw text files to produce a set of separate ads, complete with job titles and word content.

Discerning the Boundaries between Vacancy Postings In the ProQuest data set, the advertisements on a single page are all grouped in a single text field. Our next task is to identify when one vacancy posting ends and a second posting begins. Here, certain phrases at the beginning or end of individual help wanted ads allow us to identify the boundaries between ads. We use the following three-step rule to demarcate individual ads:

- Addresses: Most job vacancy posts have the employers' addresses at the end. The first step of our algorithm marks the end of an advertisement. We are able to match zip codes, such as "Boston MA 02107," and street addresses, such as "82 DEVONSHIRE STREET."
- Ending phrases: Some phrases indicate that a job vacancy post is ending, for example: "send [...] resume," "submit [...] resume," "in confidence to," "affirmative action

⁴²Within economics, we are aware of one application of LDA, which classifies Federal Open Market Committee statements by topic. See Fligstein et al. (2014) and Hansen et al. (2017).

Table 5: Predictive Word Stems in the LDA Model

Panel A: Boston Globe Classified	
1	opportun experi work call salari year employ posit manag resum
2	offic new day avail want free inc busi servic mass
3	auto new car call ford low stereo rte price motor
4	bdrm bath kit mod new bay condo home area back
5	bdrm bay mod back avail kit bath studio call build
Panel B: Boston Globe Display	
1	system experi comput opportun year manag engin program requir design
2	reg save store size price color style set regular charg
3	car price new auto power tire stereo air door stock
4	day free new one call coupon travel per offer week
5	street open inc ave mass call rte rout new home
Panel C: New York Times Classified	
1	resum seek call must work exp excel new salari send
2	new home owner acr call car hous den area ask
3	build ave new park call studio east avail fee fir
Panel D: New York Times Display	
1	experi manag system comput new opportun program requir year salari
2	school sat sun new call music ticket program wed art
3	day hotel travel free night includ new call per beach
4	one get make new year help take like time busi
5	new room call home ave avail park build floor offic
6	new white size avenu black store fifth floor wool open
7	free call new order phone charg card pleas send mail
8	rate new fund bank invest offer inc may compani interest
9	ave new street avenu park plaza unit east mall twin
10	car new call auto leas drive mile dealer power price
11	new book time world art film one magazin page news
12	price reg save design color set furnitur store select rug
Panel E: Wall Street Journal Classified	
1	experi resum salari opportun posit year market requir send develop
2	acr home call room new view beach pool bath hous
3	estat real properti offic leas locat unit call build new
4	busi street journal box wall call compani servic new avail
5	new call air owner price interior avail number ad car

employer,” “equal opportunity;” or “equal opportunities.” The algorithm marks the end of an advertisement if any of these patterns is detected and starts a new one after the following line.

- Beginning of the posts: A job vacancy post usually starts with a job title, which stands alone within a few lines and is uppercase. If we detect consecutive short lines of uppercase letters, we group those lines together. We then test whether the lines are a job title (see below). If so, the algorithm assigns the beginning of an advertisement here.

Identifying the Advertisement’s Job Title Finally, since one of the main goals of the project is to identify how individual occupations’ skill profiles have changed over time, it will be necessary to assign each vacancy posting to its corresponding occupation. On their website, O*NET publishes, for each occupation, a “Sample of Reported Job Titles.” We retrieve these titles, a list of more than eight thousand, from the O*NET website. From this list of titles, we construct a list of one-word personal nouns. For instance, “Billing, Cost, and Rate Clerks” is a potential job title according to O*NET; see <http://www.onetonline.org/link/summary/43-3021.02>. Since it is exceedingly unlikely that this exact phrase appears in any of our ads, we identify a potential job title to appear when the word “Clerk” is mentioned.

Then, in each line in which either i) words are all-capitalized or ii) only one or two words appear, we search among the words in that line of advertisement text for a personal-noun job title. According to our example in Figure 17, below, this would occur in the lines containing “MUTUAL FUNDS CLERKS,” “DEVONSHIRE STREET BOSTON MA 02109,” “PAYMENTS CLERKS,” “TERMINAL OPERATOR,” “Fidelit,” “Group,” and “111.” The first four examples would satisfy criterion (i). The lines with “MUTUAL FUNDS CLERKS,” “PAYMENTS CLERKS,” and “TERMINAL OPERATOR,” also contain a personal-noun job title. As a result, the contents of these lines are reported as the ads’ job titles.

An Example Figure 17 presents a snippet of the raw text from a page of display ads from the 1979 *Boston Globe*. This text refers to three vacancy postings, one for a “Mutual Fund Clerk” position, a second for a “Payments Clerk,” and a third for a “Terminal Operator.” As the left panel of Figure 17 makes clear, while the text contains a high frequency of transcription errors (due to the imperfect performance of ProQuest’s optical character recognition technology), there is still quite a lot of information to be extracted. Common work activities such as typing, processing applications, or maintaining client records are mentioned. In addition, one of the three advertisements includes an experience requirement.

Table 6 presents the result of our procedure applied to the unprocessed text from Figure 17. At least in this small snippet of text, our algorithm is able to correctly parse job titles

Figure 17: Unprocessed Text from the *Boston Globe*, November 4, 1979, Display Ad #133

rapid growth through continued innovation and diversification If you are highly motivated person who takes pride in your work and the company you work for consider career with Fidelity \n MUTUAL FUNDS CLERKS \n Individuals with 1-2 years funds transfer experience to process Keogh IRA accounts and adjustments \n PAYMENTS CLERKS \n Varied les processing new account applications and payments \n \n StI nt flt ner fr nlr ct tfl \n Mnirk \n and maintaining client \n strong record-keeping 50 wpm \n Data Control Department \n sorting and \n Brokerage \n environments with \n benefits package for our Boston convenient to the Market \n \n gr WilnliE lU5lty \n success \n -l 1?Q1.a1 ol P-1S1lv MPloV \n Fidelit \n Group \n 82 DEVONSHIRE STREET BOSTON MA 02109 \n 111 \n -l \n \n TERMINAL OPERATOR \n \n Position involves typing policy related information Into computer terminal No previous computer experience required Typing 5055 wpm Excellent benefits plus work Incentive program in addition to starting salary of S150-165.

Notes: The figure presents text from the first three vacancy postings in a page of display ads in the *Boston Globe*. An “\n” refers to a line break.

and identify the boundaries between the three advertisements. In identifying the boundary between the first and second ad, line breaks before “payments clerks” were helpful. In addition to these line breaks, an address—82 Devonshire Street, Boston MA 02109—helps identify the boundary between the second and third job posting. Finally, our spell-checker is able to fix some transcription errors. At the same time, even after processing, a few transcription errors remain. Moreover, because part of the text of the first job ad appears before the job title, it is not included with the remaining text for the “mutual funds clerks” position.

C.3 Details on the Continuous Bag of Words Model

The goal of the continuous bag of words (CBOW) model is to compute the similarity among words or phrases in our corpus. The first three subsections of this appendix provide a basic set up of such a model, drawing from Section 2 of Bengio et al. (2003). After this, we describe how we use our estimated continuous bag of words model to link job titles to SOC codes and job ad text to categories of occupational characteristics.

Notation and Terminology

1. A *word*, w_i , is a unit of text.
2. A *vocabulary*, V , is a set of all possible words.
3. A *corpus* is a sequence of words denoted by $\{w_1, w_2 \dots w_T\}$.
4. A *context* of a word is a set of adjacent words of predetermined distance. For our model, a context of a word w_i is $\mathcal{H} = \{w_{i-1}, w_{i-2}, \dots, w_{i-n}, w_{i+1}, \dots, w_{i+n}\}$, a set of $2n - 1$

Table 6: Processed Text from the *Boston Globe*, November 4, 1979, Display Ad #133

job title	text
	rapid growth through continued innovation and diversification If you are highly motivated person who takes pride in your work and the company you work for consider career with Fidelity
mutual funds clerks	individuals with 1 2 years funds transfer experience to process Keogh IRA accounts and adjustments
payments clerks	varied Les processing new account applications and payments stir nt flt near fr NLRB ct t fl mnirk and maintaining client strong record keeping 50 wpm data control department sorting and brokerage environments with benefits package for our Boston convenient to the market gr Willie lu5lty success 1 1 q1 a1 ol p 1sl1 vmplov fidelity group 82 devonshire street Boston ma 02109
terminal operators	position involves typing policy related information into computer terminal no previous computer experience required typing 5055 wpm excellent benefits plus work incentive program in addition to starting salary of 150 165

Notes: The table presents text from the first three of the 12 vacancy postings in a page of display ads in the *Boston Globe*.

words which appear within a n -word window of w_i .

Model Setup and Estimation

The underlying assumption in the continuous bag of word model is that words in similar contexts share semantic meaning in the population of text data. In the CBOW model, similar context refers to a set adjacent words, typically a fixed number of n words surrounding the word.⁴³

The objective, which we will try to maximize via maximum likelihood, is given by the probability of observing a word w_t conditional on the features of the words in its context $C(\mathcal{H})$. Below, we will use $\hat{P}(w_i|C(\mathcal{H}))$ to denote this probability (which is our MLE objective). The model estimation can be divided into two parts:

1. A mapping C from each word w_i in V to a real vector of predetermined length N . Here N will be parameter we are free to choose, describing how many features to include in our model to describe each individual word. In practice, C is a $|V|$ by N dimensional matrix.
2. A function g which maps a sequence of C words in the context to a conditional probability distribution over words. $\hat{P}(w_i|C(\mathcal{H})) = g(w_i, C(w_{j1}), C(w_{j2}), \dots)$, where all of the j belong to \mathcal{H} . In practice, g can be represented as a N by $|V|$ matrix for each possible context \mathcal{H} .

⁴³ However, given the same set of adjacent words, the order does not matter. For example, if the window size is 1, then, the context $[\dots, w_1, \bar{w}, w_2, \dots]$ is the same as $[\dots, w_2, \bar{w}, w_1, \dots]$ for any word \bar{w} .

In these two steps, we are predicting the likelihood of observing a particular word w_i based on the features of the words that surround it. Our model will yield a good representation of the words in our vocabulary if they accurately and parsimoniously describe the attributes of these words. The maximum likelihood procedure chooses C and g to match conditional probabilities observed in the corpus. Though the idea is relatively simple, the dimensionality of the model requires additional adjustments to reduce the computational burden. To this end, we follow the procedure as mentioned in Mikolov et al. (2013a; 2013b). We choose the dimension of C to be 300, and the context of word w_i to include the five words succeeding and preceding each w_i . In writing out of MLE objective function, we omit words w_i which appear fewer than five times in our corpus.⁴⁴

Construction of the CBOW Model

As part of a separate ongoing project, EMSI has provided us a wide sample of job ads posted online between October 2011 and March 2017. As with our newspaper data, these text contain a job title for each vacancy posting. Using our sample of text from the *Boston Globe*, *New York Times*, and *Wall Street Journal* and the entries from sample of 4.2 million job ads that were posted in January 2012 or January 2016, we construct a continuous bag of words model, applying the procedure outlined in the previous subsection. The output of this model is a vector representation, C , for each word. A phrase, too, can be represented as a vector, as the sum of the vectors of the phrase’s constituent words. For example, we will find it useful to construct a vector representation of a phrase like “construction manager.” To do so, we would simply sum the vectors for “construction” and “manager.”

With our estimate of C we use a cosine similarity score: $\frac{C(w_i) \cdot C(w_j)}{|C(w_i)| |C(w_j)|}$ to compute similarity between two words (or phrases) w_i and w_j . We use this similarity score for two purposes: to link job titles to SOC codes, and to link the words used in the body of job ads to categories of work characteristics. In the following two subsections, we detail these two applications of our CBOW model.

Grouping Occupations and Mapping Them to SOC Codes

In the newspaper data, postings for the same occupation appear via multiple distinct job titles. For example, vacancy postings for registered nurses will be advertised using job titles which include “rn,” “registered nurse,” or “staff nurse.” These job titles all map to the same occupation: 291141 using the BLS Standard Occupational Classification (SOC) system, or 3130 according to the 2000 to 2009 vintage of the Census Occupation Code. To group job titles to occupation codes, we apply the BLS SOC code. We first lightly edit job titles to

⁴⁴Mikolov et al. (2013a) estimated a model using text from a Google News corpus, and found that increasing the dimensionality of the model’s vector representation from 300 to 600 led to only small improvements in performance.

reduce the number of unique titles: We combine titles which are very similar to one another (e.g., replacing “host/hostesses” with “host,” and “accounting” with “accountant,” etc.); replace plural person nouns with their singular form (e.g., replacing “nurses” with “nurse,” “foremen” with “foreman,” etc.); and remove abbreviations (e.g., replacing “sr” with “senior,” “asst” with “assistant,” and “customer service rep” with “customer service representative”).

From this shorter list, we apply a *continuous bag of words* model in combination with an ancillary data set provided to us by EMSI (see Bengio et al., 2003, and Mikolov et al., 2013a; 2013b). Generally speaking, a continuous bag of words model is based on the idea that words or phrases are similar if they themselves appear (in text corpora) near similar words. For example, to the extent that “nurse” and “rn” both tend to appear next to words like “patient,” “medical,” or “acute” one would conclude that “nurse” and “rn” have similar meanings to one another. Building on this idea, a continuous bag of words model represents each word as a (long) vector, with the elements in each vector measuring the frequency with which other words are mentioned nearby (e.g., for the “nurse” vector, what fraction of the time in our corpus of vacancy posting text are “aardvark,” “abacus,” ... “zoo,” or “zygote” mentioned in close proximity to the word “nurse”?). Given this vector representation, two words are similar if the inner product of their vectors is large. Short phrases, too, can be usefully represented as vectors as the sum of the vectors of the constituent words (for example, the vector representation of “construction manager” would equal the sum of the “construction” and “manager” vectors.) Taking stock, with the continuous bag of words model, we can represent any phrase—and, in particular, any job title—as a vector. As a result, we can also compute the similarity of any two job titles, as the inner product of the job titles’ associated vectors.

Manually retrieving SOC codes for all of the job titles in our data set would be infeasible. There are, after all, more than 430 thousand unique job titles which are mentioned in at least two job ads, and nearly 99 thousand unique job titles which are mentioned in at least five job ads. We retrieve SOC codes using our continuous bag of words model. In particular, for each job title \mathcal{N} in our newspaper data, we compute the similarity between \mathcal{N} and all of the job titles, \mathcal{O} , which appear in O*NET’s (version 22.1) either Sample of Reported Titles or Alternate Sample of Reported Titles. For each O*NET job title \mathcal{O} , we observe an SOC code. So, for the job title \mathcal{N} , we assign to \mathcal{N} the SOC code of the O*NET job title \mathcal{O} closest to \mathcal{N} . We do this for any job title that appears at least twice in our newspaper data.

In a second step, we assign an SOC code of 999999 (“missing”) if certain words or phrases appear — “associate,” “career builder,” “liberal employee benefit,” “many employee benefit,” or “personnel” — anywhere in the job title, or for certain exact titles: “boys,” “boys boys,” “men boys girls,” “men boys girls women,” “men boys men,” “people,” “professional,” or “trainee.” These words and phrases appear commonly in our newspaper ads and do not refer to the SOC code which our CBOW model indicates. “Associate” commonly appears the part of the name of the firms which are placing the ad. “Personnel” commonly refers to the

personnel department to which the applicant should contact.

We also replace the SOC code for the job title “Assistant” from 399021 (the SOC code for “Personal Care Aides”) to 436014 (the SOC code for “Secretaries and Administrative Assistants”). “Assistant” is the third most common job title, and judging by the text within the job ads refers to a secretarial occupation rather than one for a personal care worker. While we are hesitant to modify our job title to SOC mapping in an ad hoc fashion for any job title, mis-specifying this mapping for such a common title would have a noticeably deleterious impact on our data set.

In a final step, we amend the output of the CBOW model for a few ambiguously defined job titles. These final amendments have no discernible impact on aggregate trends in task content, on role within-occupation shifts in accounting for aggregate task changes, or on the role of shifts in the demand for tasks in accounting for increased earnings inequality. First, for job titles which include “server” and which do not also include a food-service-related word — banquet, bartender, cashier, cocktail, cook, dining, food, or restaurant — we substitute an SOC code beginning with 3530 with the SOC code for computer systems analysts (151121). Second, for job titles which contain the word “programmer,” do not include the words “cnc” or “machine,” we substitute SOC codes beginning with 5140 or 5141 with the SOC code for computer programmers (151131). Finally, for job titles which contain the word “assembler” and do not contain a word referring to manufacturing assembly work — words containing the strings “electronic,” “electric,” “machin,” “mechanical,” “metal,” and “wire” — we substitute SOC codes beginning with 5120 with the SOC code of computer programmers (151131). The amendments, which alter the SOC codes for approximately 0.2 percent of ads in our data set, are necessary for ongoing work in which we explore the role of new technologies in the labor market. Certain words refer both to a job title unrelated to new technologies as well as to new technologies. By linking the aforementioned job titles to SOCs that have no exposure to new technologies, we would be vastly overstating the rates at which food service staff or manufacturing production workers adopt new ICT software. On the other hand, since these ads represent a small portion of the ads referring to computer programmer occupations, lumping the ambiguous job titles with the computer programmer SOC codes will only have a minor effect on the assessed technology adoption rates for computer programmers.

Eliciting Skill- and Task-Related Information

Within the body of the job ads, similar words will refer to a common task or skill. For example, mathematical skills could appear in job ads using the words “mathematics,” “math,” or “quantitative.” To study occupations’ evolving skill requirements and task content, it is necessary to categorize these occupational characteristics into a manageable number of groups. Here, we construct three classification schemes.

Our main classification follows that of [Spitz-Oener \(2006\)](#) who, in her study of the chan-

ging task content of German occupations, groups activities into five categories: *nonroutine analytic*, *nonroutine interactive*, *nonroutine manual*, *routine cognitive*, and *routine analytic*. In our main application of her categorizations, we begin with the words in each of her five lists of task-related words. For each list, we append words which are similar to those in footnote 11, where similarity is determined by our continuous bag of words model: We append words which have a cosine similarity greater than 0.55 to any of the words in footnote 11. We also append any additional words which have one of the ten highest cosine similarity scores in each task group. This is our primary classification, and we use it in each calculation that follows in the paper. In addition, as a robustness check, we will consider a narrower mapping between categories and words, one which only relies in [Spitz-Oener \(2006\)](#)'s definitions as enumerated in footnote 11.

For varying purposes, we also consider two additional complementary classifications. First, with the aim of emulating O*NET's database, we construct our own classification between words and phrases on the one hand and occupational work styles (corresponding to O*NET Elements beginning with 1C), skills (encompassing O*NET Elements 2A and 2B), knowledge requirements (corresponding to O*NET Elements 2C), and work activities (O*NET Elements 4A) on the other. For each O*NET Element, we begin by looking for words and phrases related to the O*NET Title and, refer to the O*NET Element Description to judge whether these synonyms should be included, as well as if other words should be included. For instance, for the "Production and Processing" knowledge requirement, our list of synonymous words includes the original "production" and "processing," as well as "process," "handle," "produce," "render," and "assembly." And since the O*NET Description for "Production and Processing" states that the skill is associated with the "Knowledge of raw materials, production processes, quality control, costs, and other techniques for maximizing the effective manufacture and distribution of goods," we also include "quality control," "raw material," "qc," and "distribution" in our list of words and phrases to search for when measuring this knowledge requirement. Admittedly, since this procedure is based on our own judgment, it is necessarily ad hoc. Moreover it will not be able to capture all of the words phrases which are indicative of a particular work style, skill, knowledge requirement, or work activity.

For this reason, we append to our initial lists of words and phrases an additional set of words, using a continuous bag of words model similar to the one constructed in Section 2.2, built from the newspaper (1960 to 2000) and online (January 2012 and January 2016) job ads. We compute the similarity of the words in each O*NET Element Title and all of the other words in our corpus of newspaper and online vacancy postings. For instance, for "Production and Processing," our model yields: "process," "processes," "packaging," "preparation," and "manufacturing" as the words with the highest cosine similarity. We take the top 10 words, plus any additional words which have a cosine similarity greater than 0.45, to the O*NET Element Title and add these words to those words and phrases from our "judgment-based"

procedure described in the previous paragraph.

Each of the two approaches, the “judgment based” procedure and the “continuous bag of words model based” procedure, has its strengths and weaknesses. On the one hand, the first procedure is clearly ad hoc. Moreover, the continuous bag of words model has the advantage of accounting for the possibility that employers’ word choice may differ within the sample period.⁴⁵ On the other hand, there is a danger that the continuous bag of words model will identify words to be similar even if they are not synonymous. For example, the vector representations in our bag of words model indicates that the five most similar words to the “Mathematics” O*NET Element Title are “math,” “physics,” “economics,” “algebra,” and “science.” While the first five words strike us as reasonable, a word like “linguistics” (which also appears in the list of similar words according to the CBOW model) does not. In our job ads, since (apparently) mathematics and linguistics are mentioned in similar contexts, our model suggests that these words have similar meaning when in fact they do not.

Our second classification scheme applies the mapping between keywords and skills which [Deming and Kahn \(2017\)](#) define in their study of the relationship between firms’ characteristics and the skill requirements in their vacancy postings.⁴⁶ To each of these lists of words, we append additional words which are sufficiently similar (those with a cosine similarity greater than 0.55 or among the 10 most similar words for each category) to any of the words in the original list.

D Sensitivity Analysis Related to Sections 3 and 4

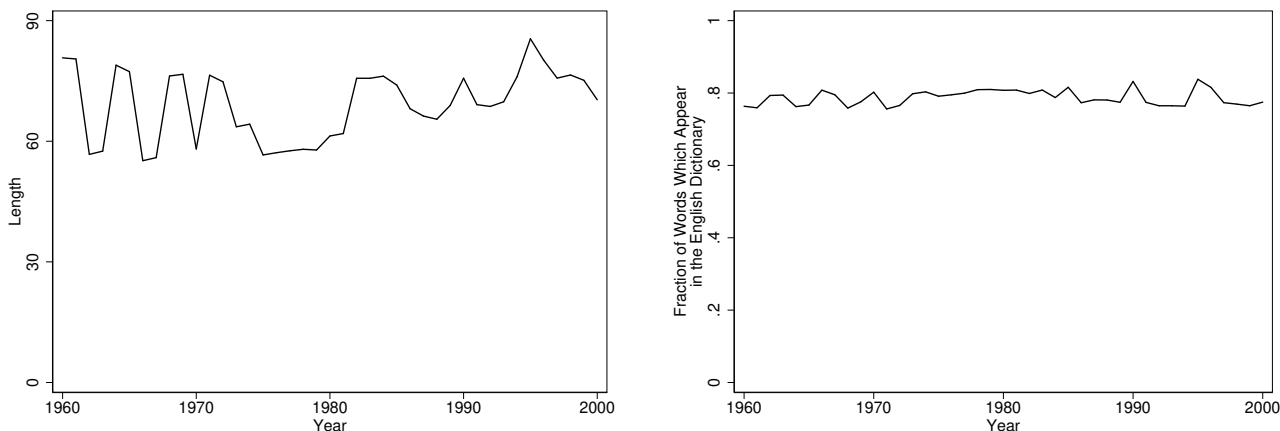
D.1 Trends in Ad Length and Spelling Accuracy

In Figure 18, we plot the average length of each ad, and the fraction of correctly spelled words for each ad. These plots indicate that there is a weak upward trend in ad length over our sample period — the average number of words per ad in our data set is 69.6 in the

⁴⁵For instance, even though “creative” and “innovative” largely refer to the same occupational skill, it is possible that their relative use among potential employers may differ within the sample period. This is indeed the case: Use of the word “innovative” has increased more quickly than “creative” over the sample period. To the extent that our ad hoc classification included only one of these two words, we would be mis-characterizing trends in the O*NET skill of “Thinking Creatively.” The advantage of the continuous bag of words model is that it will identify that “creative” and “innovative” mean the same thing because they appear in similar contexts within job ads. So, even if employers start using “innovative” as opposed to “creative” part way through our sample, we will be able to consistently measure trends in “Thinking Creatively” throughout the entire period. A second advantage of our CBOW model is that it allows us to partially undo the transcription errors generated in ProQuest’s image scanning. Our CBOW algorithm, for example, identifies “adverhsng” as synonymous “advertising.”

⁴⁶See Table 1 of [Deming and Kahn \(2017\)](#) for their list of words and their associated skills. Building on their definitions, we use the following rules 1) cognitive: analytical, cognitive, critical thinking, math, problem solving, research, statistics; 2) social: collaboration, communication, negotiation, presentation, social, teamwork; 3) character: character, energetic, detail oriented, meeting deadlines, multi-tasking, time management; 4) writing: writing; 5) customer service: client, customer, customer service, patient, sales; 6) project management: project management; 7) people management: leadership, mentoring, people management, staff, supervisory; 8) financial: accounting, budgeting, cost, finance, financial; 9) computer (general): computer, software, spreadsheets.

Figure 18: Trends in Ad Length, Fraction of Correctly Spelled Words



Notes: The left panel plots the average length (including both words that appear in the English dictionary and those that do not). The right panel plots the fraction of words within each ad that are English-dictionary words. The correlation between year and ad length is 0.27 (with a p-value of 0.088), and between year and the fraction of words which are correctly spelled is 0.09.

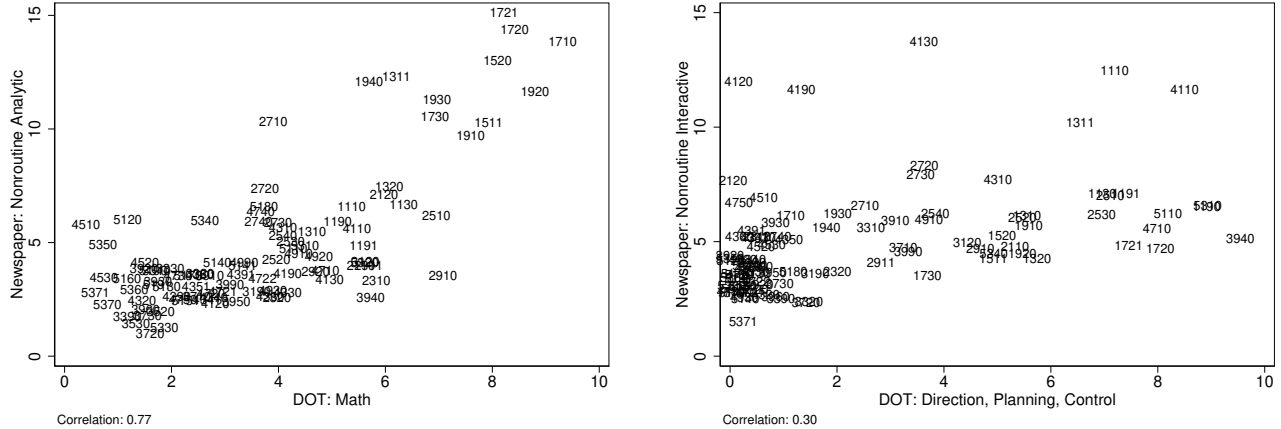
1960s, 62.4 in the 1970s, 69.3 in the 1980s, and 74.8 from 1990 to 2000 — and that there is no trend in the fraction of words that are correctly spelled (i.e., words that are in our English dictionary). The motivation for these plots is that any time-varying measurement error in our newspaper text would manifest as trends in the share of correctly spelled words. Reassuringly, no such trend is apparent.

D.2 Comparison to the Dictionary of Occupational Titles

In this appendix, we compare our newspaper text based nonroutine and routine task measures to those measures introduced in [Autor, Levy, and Murnane \(2003\)](#). As far as we are aware, the 1977 and 1991 Dictionary of Occupational Titles (DOT) — which are the underlying source of the Autor, Levy, and Murnane measures — are the sole data set from which one could potentially measure within-occupation changes in U.S. task content over our sample period.

First, we compare our newspaper measures to the analogous measures in a single vintage of the DOT. In the left panel of [Figure 19](#), we plot the relationship between the Dictionary of Occupational Titles GED Math measure and our newspaper-based nonroutine analytic task measure. From both data sets, we take values from 1977. The correlation between the two measures is 0.77. According to both data sets, engineering and computer-related occupations are those that have the highest nonroutine analytic task content. In the right panel of [Figure 19](#), we present the analogous relationship for nonroutine interactive task measures. Here, the correlation is 0.30. The correlations for the other three measures are 0.44 for nonroutine manual tasks, 0.41 for routine cognitive tasks, and -0.03 for routine manual tasks. So, for

Figure 19: Comparison of DOT and Newspaper Task Measures: 1977 Levels



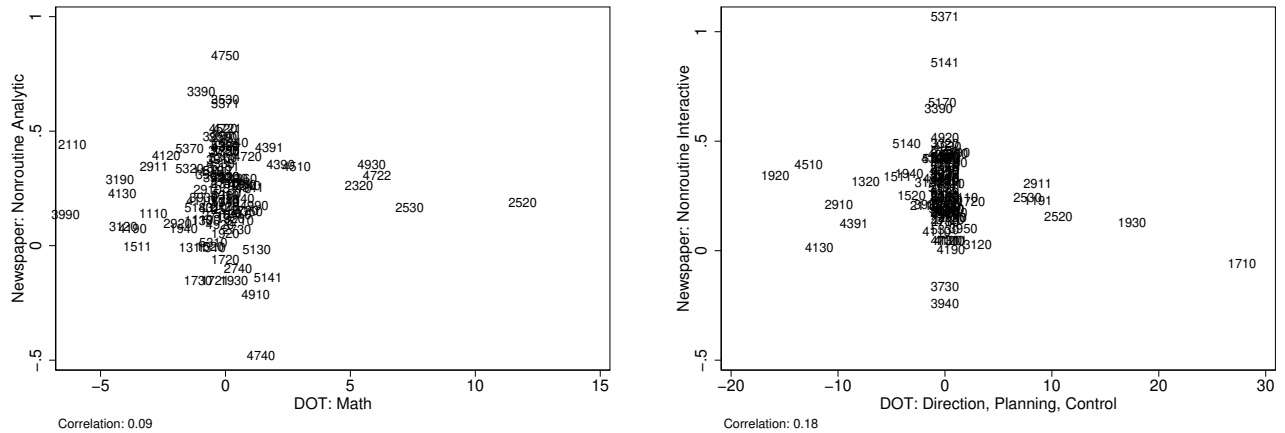
Notes: The left panel gives the relationship between the DOT GED Math variable with our newspaper-based nonroutine analytic task measure (stated as number of mentions per 1000 job ad words). The right panel presents the same relationship for the DOT Direction, Planning, and Control measure and our newspaper-based nonroutine interactive task measure. The numbers within the scatter plot characterize the SOC code. The stated correlation is computed with weights given by the newspaper number of job ads per occupation as of 1977.

four out the five task groups, our newspaper-based task measures align at least moderately with those in the DOT.

While there is a moderate but substantial accordance in levels between our newspaper-based task measures and the DOT measures, no such concordance exists when looking at task growth rates. According to the DOT, from 1977 to 1991 there was a decline in nonroutine analytic tasks within occupations; routine manual tasks increased within occupations (see the bottom row of Table 6 of [Autor, Levy, and Murnane, 2003](#)). This is the opposite of what we find. Moreover, the correlation in occupations' changes in task intensity, from 1977 to 1991, is much weaker when comparing the two data sets. Figure 20 plots the correspondence for nonroutine analytic (left panel) and nonroutine interactive (right panel) tasks. For the five task measures, the correlations in growth rates in task intensities are: 0.09 (for nonroutine analytic tasks), 0.18 (nonroutine interactive), 0.01 (nonroutine manual), 0.02 (routine cognitive), and -0.04 (routine manual). Overall, there is essentially no relationship between the growth rates of DOT task measures and the growth rates of our newspaper-based task measures.

To investigate further the divergence between our measured task changes and those recovered from the DOT, we plot the task measures in the 1977 and 1991 editions, in Figure 21. This figure indicates that, for a large fraction of occupations, the GED Math measure (left panel) and the Direction, Planning, and Control measure (right panel) are essentially the same across DOT editions. The correlations for the three un-plotted tasks are 0.95 for Fin-

Figure 20: Comparison of DOT and Newspaper Task Measures: 1977 to 1991 Growth Rates



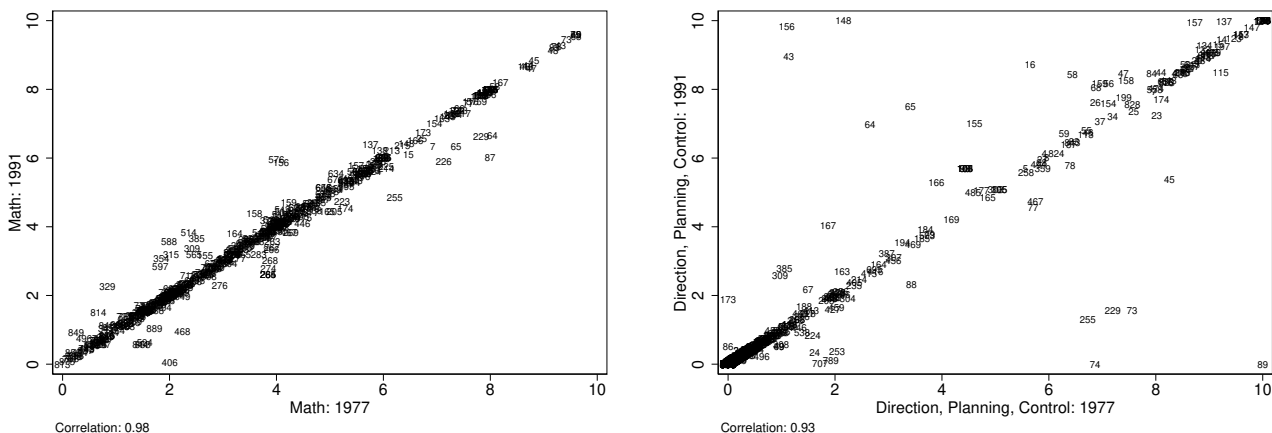
Notes: The left panel gives the relationship between the DOT GED Math variable with our newspaper-based nonroutine analytic task measure (stated as a growth rate between 1977 and 1991). The right panel presents the same relationship for the DOT Direction, Planning, and Control measure and our newspaper-based nonroutine interactive task measure. The numbers within the scatter plot depict the SOC Code. The stated correlation is computed with weights given by the number of newspaper job ads per occupation as of 1977 and 1991.

ger Dexterity; 0.95 for Eye, Hand, and Foot Coordination; and 0.87 for Setting Tolerances.⁴⁷ These correlations, especially those for the GED Math variable, are suggestive of irregular and incomplete updating of occupations’ task content measures between 1977 and 1991. It’s hypothetically possible that there were actually no task changes, within occupations, for a large number of occupations. This point of view, however, is inconsistent [National Research Council \(1999\)](#) and [Spitz-Oener \(2006\)](#). (To emphasize, for the empirical exercise that [Autor, Levy, and Murnane \(2003\)](#) perform — namely measuring the relationship between occupations’ task content changes and changes in computer adoption rates — the fact that many task measures were not updated by DOT examiners does not pose a problem. However, these plots do indicate that the DOT is ill-suited in measuring within-occupation changes in task content for a broad swath of occupations.)

To sum up, in this appendix we make two arguments, each in a different way supporting our data contribution. First, we show that our newspaper-based task measures are significantly correlated with, in the cross-section, existing measures of occupations’ nonroutine and routine tasks. Second, however, we also show that while there is little to no correlation between our measures of occupations’ task growth rates and those based on the DOT, the difference lies mainly in the incomplete updating that occurred between the 1977 and 1991 versions of the DOT.

⁴⁷ The unweighted correlations are higher than the weighted correlations by 0.02, on average.

Figure 21: Comparison of 1977 and 1991 DOT



Notes: The left panel gives the relationship, according to the 1977 and 1991 editions of the DOT, of occupations’ GED Math variable. The right panel presents the same relationship for the DOT Direction, Planning, and Control measure. The numbers within the scatter plot are the 1980-90 occupation code, as defined by Autor, Levy, and Murnane. The stated correlation is computed with employment weights, given by summing across individuals working in each occupation as sampled in the 1984 CPS.

D.3 Representativeness of Boston and New York Job Ads

Our newspaper data contain information almost exclusively about vacancies in the New York City and Boston metro areas. We used this information about New York City and Boston ads to characterize the skill and task content of jobs throughout the United States. This discrepancy could potentially be problematic, especially since workers in New York City and Boston are not representative of U.S. workers more generally. Workers in these metro areas tend to have higher education, are paid higher wages, and are over-represented in certain types of occupations (e.g., in financial management, in tertiary education, etc) and under-represented in others. What is more, this non-representativeness may be growing over time (for example, the college graduate share in New York City and Boston has increased faster than in other parts of the country.)

Unfortunately, we cannot examine — based on our newspaper data — whether our occupations’ task measures are substantially different in Boston and New York compared to the rest of the United States. However, we have a sample of text from vacancy postings from a more recent period, from October 2011 to March 2017, from which we can examine the representativeness of Boston and New York. Our sample is drawn from a 5 percent sample of ads, 7.6 million ads, which were collected by EMSI.⁴⁸

To do so, we begin by computing our nonroutine and routine task measures, using the same mapping between words and task groups that we use in the rest of the paper. We then

⁴⁸For this exercise, we drop the first three months — October 2011 to December 2011 — as the number of ads collected per month is rapidly expanding over the very beginning of the EMSI sample period (suggesting that, relative to the rest of the sample period, the samples in the first few months may not be representative.)

perform a set of regressions characterized by the following equation:

$$\text{task}_{ajt}^h = \beta_h \cdot 1_{a \in \{\text{Boston, New York}\}} + \iota_{jh} + \iota_{th} + \iota_{sh} + \epsilon_{ahjt}. \quad (11)$$

In Equation 11, h refers to one of five routine and nonroutine task categories; task_{ajt}^h equals the number of mentions of task h (relative to the number of words in the ad) in a , published in year t , for an occupation j ; ι_{jh} , ι_{th} , and ι_{sh} respectively refer to occupation fixed effects, year fixed effects, and fixed effects for the job message board from which EMSI procured the data.⁴⁹ The coefficient of interest is β_h , characterizing the relative frequency of task h in the Boston and New York metro areas, relative to the rest of the U.S. We conduct regressions with increasingly detailed occupation fixed effects. These regressions will allow us to assess the extent to which, for example, Engineers in New York and Boston differ from those in the rest of the U.S. (using a 4-digit SOC fixed effect), Electrical Engineers in New York and Boston are unique (using a 6-digit SOC fixed effects), or Wire Design Installation Engineers in New York and Boston are unique (using job title fixed effects.)

The results from this exercise are given in Table 7. We find substantial differences in the overall task content of Boston and New York jobs, relative to the rest of the country. Per thousand job ad words, there are 0.39 additional nonroutine analytic task words (0.058=0.39/6.63 standard deviations) and 0.30 nonroutine interactive task words (0.062 standard deviations) in Boston and New York. However, much of the differences are due to the fact that the occupational mix of Boston and New York are different from that of the country as a whole (as opposed to individual occupations differing in their task content). Using 4-digit SOC fixed effects, the nonroutine analytic and interactive task content of jobs in New York and Boston are higher by 0.025 and 0.032 standard deviations, respectively. Using more detailed fixed effects, at the level of 6-digit SOC codes or job titles, leads to even smaller discrepancies between our two metro areas and the rest of the U.S.

We are not only specifically interested in the level of non-representativeness of our New York and Boston newspaper text, but also in trends in non-representativeness over our 1960 to 2000 sample period. In fact, since our contribution relates to within-occupation trends in task content, trends in non-representativeness of New York and Boston would be especially problematic. For the short (five-year) period from which we have on-line job ad text, we can examine whether there are any trends in the task content of New York and Boston job relative to jobs in other portions of the U.S. To this end, we examine regressions characterized by the following equation:

⁴⁹As the sample period has progressed, EMSI has collected job ad text from an increasingly wide variety of job posting websites. We include website-specific fixed effects to account for the changing composition over the period.

Table 7: Estimates from Equation 11

Fixed Effect	Nonroutine Analytic	Nonroutine Interactive	Nonroutine Manual	Routine Cognitive	Routine Manual
None	0.387 (0.012)	0.386 (0.011)	-0.122 (0.004)	-0.009 (0.004)	0.050 (0.003)
4-digit SOC	0.168 (0.011)	0.199 (0.010)	-0.084 (0.004)	-0.016 (0.004)	0.065 (0.003)
6-digit SOC	0.102 (0.010)	0.196 (0.010)	-0.082 (0.004)	-0.022 (0.003)	0.055 (0.003)
Job Title	-0.018 (0.009)	0.083 (0.009)	-0.064 (0.004)	-0.012 (0.003)	0.025 (0.002)
Mean of h	5.439	5.227	1.048	0.615	0.249
Std. Dev. of h	6.629	6.254	2.474	2.021	1.560

Notes: Each column presents the coefficient estimates, standard errors, and sample statistics of one of our five Spitz-Oener task measures. The first four set of rows present coefficient estimates and standard errors of β_h , with each set of rows applying a different occupation fixed effect. The sample in these regressions includes the job ads for which we could retrieve an SOC code based on the ad’s job title, 5.4 million job ads. The final two rows present the average and standard deviation of the task measure in our sample of 5.4 million ads.

$$\text{task}_{ajt}^h = [\beta_h + \gamma_h \cdot (t - 2012)] \cdot 1_{a \in \{\text{Boston, New York}\}} + \iota_{jh} + \iota_{th} + \iota_{sh} + \epsilon_{ahjt} \quad (12)$$

The parameter of interest in Equation 12 is γ_h ; it characterizes the growth rate in task h mentions over the sample period in Boston and New York compared to the rest of the U.S. As before, inclusion of occupation fixed effects tends to reduce the magnitude of the γ_h coefficients. The one coefficient estimate of γ_h that is most indicative of substantial trends in the non-representativeness of New York and Boston jobs is that of routine manual tasks with job title 4-digit or 6- digit SOC fixed effects. Under this specification, ads from Boston and New York (relative to the rest of the United States) mentioned an additional 0.10 (=0.020·5) routine manual task words (per thousand job ad words) in 2017 relative to 2012. This difference represents 0.064 standard deviations of the routine manual task measure. For the other four task measures, the trend in the difference between Boston and New York task mentions and task mentions in the rest of the country is at most 0.011 standard deviations of the task measure.

Overall, while there are statistically significant differences in ads posted in Boston and New York, relative to the U.S., these differences largely exist between occupations rather than within occupations. Moreover, the differences between New York and Boston and the rest of the U.S. are modest, when compared to the overall dispersion in task measures, across all on-line job ads.

Table 8: Estimates from Equation 12,

Fixed Effect		Nonroutine Analytic	Nonroutine Interactive	Nonroutine Manual	Routine Cognitive	Routine Manual
None	β_h	0.344 (0.026)	0.293 (0.025)	-0.169 (0.010)	-0.037 (0.008)	-0.023 (0.006)
	γ_h	0.015 (0.008)	0.032 (0.008)	0.017 (0.003)	0.010 (0.003)	0.026 (0.002)
4-digit	β_h	0.143 (0.024)	0.162 (0.023)	-0.091 (0.009)	-0.029 (0.008)	0.008 (0.006)
	γ_h	0.009 (0.008)	0.013 (0.007)	0.002 (0.003)	0.005 (0.003)	0.020 (0.002)
6-digit	β_h	0.059 (0.023)	0.141 (0.023)	-0.088 (0.009)	-0.036 (0.008)	0.003 (0.006)
	γ_h	0.015 (0.007)	0.019 (0.007)	0.002 (0.003)	0.005 (0.002)	0.018 (0.002)
Job Title	β_h	-0.050 (0.021)	-0.010 (0.020)	-0.049 (0.008)	-0.006 (0.007)	0.005 (0.005)
	γ_h	0.011 (0.006)	0.033 (0.006)	-0.005 (0.003)	-0.002 (0.002)	0.007 (0.002)
Mean of h		5.439	5.227	1.048	0.615	0.249
Std. Dev. of h		6.629	6.254	2.474	2.021	1.560

Notes: Each column presents the coefficient estimates, standard errors, and sample statistics of one of our five Spitz-Oener task measures. The first four sets of rows present coefficient estimates and standard errors of β_h and γ_h , with each set of rows applying a different occupation fixed effect. The final two rows present the average and standard deviation of the task measure in our sample of 5.4 million ads.

D.4 Top Occupations

In addition to the measures developed by Spitz-Oener (2006), we apply the mapping between keywords and skills that Deming and Kahn (2017) used in their study of the relationship between firms' characteristics and the skill requirements in their vacancy postings. For each skill group, we append words that are similar to those mentioned in footnote 46, using the continuous bag of words model to identify words and phrases that are similar to one another.

Table 9 lists the top occupations according to the skill groups in Deming and Kahn (2017). According to intuition, ads for sales representatives and sales managers have the highest frequency of words related to customer service skills; ads for financial specialists and managers have the highest frequency of words related to financial skills; and ads for supervisors, managers, and health diagnosticians have the highest frequency of words related to people management.

D.5 Trends in Keyword Frequencies

In Section 4.1, we considered trends in the frequency with which different groups of words were mentioned in our newspaper text. We showed that the frequency of words related

Table 9: Top Occupations According to the [Deming and Kahn \(2017\)](#) Classification of Skills

Character			Computer		
3190: Other Healthcare Support	20.9	8.8	1511: Computer	133.9	13.5
3390: Other Protective Service	11.4	8.8	5530: Military Forces	0.8	8.3
3530: Food Serving	17.4	8.4	1720: Engineers	107.8	7.2
4351: Weighers, Measurers	3.7	8.4	1520: Math. Science	9.7	6.9
3120: Physical Therapist Asst.	1.2	8.1	1721: Engineers	72.6	6.8
Customer Service			Financial		
4140: Sales Rep., Whole./Manuf	158.4	12.8	1320: Financial Specialists	204	16.2
4120: Retail Sales	131.3	10.2	1130: Operation Managers	102.7	10.5
4130: Sales Rep., Services	78.2	9.5	4330: Financial Clerks	191.7	6.3
4190: Other Sales	46.4	9.5	1520: Math. Science	9.7	5.1
1120: Sales Managers	48.8	9.0	1930: Social Scientists	17.9	5.0
People Management			Problem Solving		
1131: H.R. Managers	10.1	8.2	1520: Math. Science	9.7	9.0
3710: Cleaning Supervisors	4.1	6.7	1920: Physical Scientists	21.8	7.2
2911: Health Diagnosing	107.1	6.6	1940: Science Technicians	13	6.7
3910: Personal Care Supervisor	2.2	6.4	1910: Life Scientists	11.4	5.0
5520: Military Supervisors	0.3	6.3	1311: Business Operations	27.6	4.7
Project Management			Social		
1721: Engineers	72.6	19.6	2110: Social	59.5	2.9
1720: Engineers	107.8	19.5	1131: H.R. Managers	10.1	2.1
5520: Military Supervisors	0.3	16.6	5530: Military Forces	0.8	2.0
1710: Architects	13.8	14.7	2720: Entertainers	41	1.9
5530: Military Forces	0.8	13.6	1311: Business Operations	27.6	1.9
Writing					
2730: Media	61.4	6.7			
1930: Social Scientists	17.9	1.5			
2740: Media Equipment	13.3	1.3			
1311: Business Operations	27.6	1.3			
1120: Sales Managers	48.8	1.2			

Notes: This table lists the top five occupations according to the frequency with which different activity-related words are mentioned. Within each panel, the first column gives the SOC code and title; the second column gives the number of job ads in our data set (in thousands); and the final column gives the frequency (mentions per 1000 job ad words) of task-related words. Footnote 46 contains the words and phrases corresponding to each skill that were used in [Deming and Kahn \(2017\)](#). To these lists, we append similar words, using the continuous bag of words model introduced in Section 2.3.

to routine cognitive and routine manual tasks have declined over the sample period, while words related to nonroutine task words have increased in frequency. Moreover, nearly all of these changes have occurred within, rather than between, 4-digit SOC codes. In this appendix, we first consider alternate groups of skill- and task-related words, the first due to [Deming and Kahn \(2017\)](#) and the second due to [Firpo, Fortin, and Lemieux \(2014\)](#). Next, returning to [Spitz-Oener \(2006\)](#)'s occupation codes, we re-consider trends in task mentions with an alternate methodology for identifying task-related words and alternate occupation classifications.

In [Table 10](#), we use Deming and Kahn's categorization of skills. Computer, Customer Service, and Social skills have become increasingly prevalent with within-occupational changes, again accounting for an overwhelming proportion of these trends. For eight of the nine skills, within-occupation changes are the primary source of growth in mentions of skill related words. (For the ninth skill, Problem Solving skills, the between-occupation component is larger, but not statistically significantly so).

Next, we study within and between changes in work frequencies using the [Firpo, Fortin, and Lemieux \(2014\)](#) categorization of O*NET work activities and work contexts.⁵⁰ [Table 11](#) illustrates that words related to Information Content, Face-to-Face Contact, and Decision-Making have increased in prevalence, and that most of these changes are due to within, rather than between, occupational changes.

In the remaining tables of this subsection, we revert to the [Spitz-Oener \(2006\)](#) categorization of groups of tasks. When we produced [Table 3](#), we applied not only [Spitz-Oener \(2006\)](#) mapping between words and task groups, but also our own continuous bag of words model to identify additional words to search for. In [Table 12](#), we recompute trends in keyword frequencies, now using [Spitz-Oener \(2006\)](#)'s original mapping between words and task groups. In this table, the frequency of task-related keywords is lower than in [Table 3](#). However, the trends in keyword frequencies — increasing for nonroutine analytic and interactive tasks and decreasing for routine tasks — are similar to those depicted in [Table 3](#). Moreover, as in [Table 3](#), a large fraction of the overall changes in keyword frequencies occur within occupations, again with the partial exception of nonroutine manual tasks.

⁵⁰According to the [Firpo, Fortin, and Lemieux \(2014\)](#) categorization, the O*NET Elements associated with Information Content include codes related to Getting Information (4.A.1.a.1), Processing Information (4.A.1.a.2), Analyzing Data (4.A.2.a.4), Interacting with Computers (4.A.3.b.1), and Documenting/Recording Information (4.A.3.b.6). The elements associated with the Automation/Routine group include Degree of Automation (4.C.3.b.2), Repeating Same Tasks (4.C.3.b.7), Structured versus Unstructured Work (4.C.3.b.8), Pace (4.C.3.d.3), and Repetitive Motions (4.C.2.d.1.i). Face-to-Face Contact maps to Face-to-Face Discussions (4.C.1.a.2.1), Establishing Interpersonal Relationships (4.A.4.a.4), Caring for Others (4.A.4.a.5), Working Directly for the Public (4.A.4.a.8), and Coaching and Developing Others (4.A.4.b.5). The On-site-Job group of elements includes Inspecting Equipment, Structures, or Material (4.A.1.b.2), Handling and Moving Objects (4.A.3.a.2), Controlling Machines and Processes (4.A.3.a.3), Operating Vehicles (4.A.3.a.4), Repairing Mechanical Equipment (4.A.3.b.4), and Repairing Electronic Equipment (4.A.3.b.5). Finally, Decision-Making maps to the following O*NET Elements: Making Decisions (4.A.2.b.1), Thinking Creatively (4.A.2.b.2), Developing Objectives (4.A.2.b.4), Responsibility for Outcomes and Results (4.C.1.c.2), and Frequency of Decision Making (4.C.3.a.2.b).

Table 10: Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	A. Character				B. Computer			
1960 Level	4.13 (0.04)				1.14 (0.04)			
1960-1970	1.03 (0.05)	0.04 (0.01)	0.99 (0.05)	0.96 (0.01)	0.52 (0.04)	0.00 (0.01)	0.52 (0.04)	1.00 (0.01)
1970-1980	1.13 (0.03)	0.12 (0.01)	1.02 (0.03)	0.90 (0.01)	0.97 (0.03)	-0.06 (0.01)	1.03 (0.03)	1.06 (0.01)
1980-1990	0.36 (0.03)	0.18 (0.02)	0.17 (0.03)	0.49 (0.06)	1.32 (0.04)	-0.21 (0.03)	1.53 (0.06)	1.16 (0.02)
1990-2000	-0.78 (0.20)	-0.24 (0.15)	-0.55 (0.18)	0.70 (0.36)	0.74 (0.09)	-0.06 (0.08)	0.80 (0.13)	1.08 (0.11)
1960-2000	1.73 (0.20)	0.10 (0.16)	1.63 (0.18)	0.94 (0.08)	3.55 (0.09)	-0.32 (0.09)	3.88 (0.15)	1.09 (0.03)
	C. Customer Service				D. Financial			
1960 Level	2.79 (0.03)				1.95 (0.03)			
1960-1970	0.17 (0.03)	0.04 (0.01)	0.13 (0.03)	0.75 (0.04)	0.12 (0.03)	0.15 (0.01)	-0.03 (0.03)	-0.29 (0.25)
1970-1980	0.75 (0.02)	0.07 (0.01)	0.68 (0.02)	0.91 (0.01)	0.25 (0.02)	0.19 (0.01)	0.07 (0.02)	0.26 (0.05)
1980-1990	1.03 (0.03)	0.01 (0.02)	1.02 (0.04)	0.99 (0.02)	0.33 (0.02)	0.03 (0.02)	0.30 (0.04)	0.90 (0.05)
1990-2000	0.70 (0.08)	0.10 (0.12)	0.60 (0.16)	0.86 (0.17)	0.04 (0.07)	-0.14 (0.05)	0.18 (0.09)	4.21 (11.76)
1960-2000	2.64 (0.09)	0.22 (0.13)	2.42 (0.18)	0.92 (0.05)	0.75 (0.08)	0.23 (0.06)	0.52 (0.11)	0.69 (0.09)
	E. People Management				F. Problem Solving			
1960 Level	2.10 (0.03)				1.39 (0.04)			
1960-1970	0.66 (0.03)	0.04 (0.01)	0.62 (0.03)	0.94 (0.01)	-0.18 (0.03)	0.05 (0.00)	-0.23 (0.03)	1.27 (0.06)
1970-1980	0.61 (0.02)	0.28 (0.01)	0.33 (0.02)	0.55 (0.02)	0.01 (0.01)	0.07 (0.01)	-0.06 (0.01)	-4.98 (98.67)
1980-1990	0.10 (0.02)	0.12 (0.02)	-0.02 (0.03)	-0.21 (0.20)	0.22 (0.01)	0.06 (0.01)	0.16 (0.02)	0.73 (0.05)
1990-2000	-0.39 (0.06)	-0.27 (0.14)	-0.12 (0.15)	0.31 (0.34)	0.14 (0.03)	-0.05 (0.06)	0.20 (0.07)	1.36 (0.38)
1960-2000	0.97 (0.07)	0.17 (0.15)	0.80 (0.16)	0.83 (0.15)	0.19 (0.05)	0.13 (0.07)	0.06 (0.09)	0.34 (0.36)

Notes: Continued on the following page.

Table 10 (Continued): Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	G. Project Management				H. Social			
1960 Level	3.41 (0.09)				0.40 (0.01)			
1960-1970	0.24 (0.08)	0.11 (0.01)	0.14 (0.08)	0.56 (0.36)	0.10 (0.01)	0.03 (0.00)	0.08 (0.01)	0.76 (0.03)
1970-1980	0.65 (0.05)	0.28 (0.01)	0.37 (0.04)	0.56 (0.03)	0.45 (0.01)	0.07 (0.00)	0.37 (0.01)	0.84 (0.01)
1980-1990	0.49 (0.05)	0.11 (0.03)	0.38 (0.06)	0.78 (0.05)	0.68 (0.02)	0.10 (0.01)	0.58 (0.02)	0.85 (0.02)
1990-2000	0.53 (0.12)	-0.48 (0.18)	1.00 (0.22)	1.90 (0.34)	0.37 (0.05)	0.11 (0.03)	0.26 (0.05)	0.70 (0.08)
1960-2000	1.91 (0.16)	0.02 (0.19)	1.89 (0.28)	0.99 (0.10)	1.60 (0.06)	0.31 (0.04)	1.29 (0.06)	0.81 (0.02)
I. Writing								
1960 Level	0.50 (0.01)							
1960-1970	-0.03 (0.01)	0.05 (0.00)	-0.08 (0.01)	2.50 (0.47)				
1970-1980	0.14 (0.01)	0.02 (0.00)	0.11 (0.01)	0.84 (0.03)				
1980-1990	0.22 (0.01)	-0.03 (0.01)	0.25 (0.01)	1.13 (0.03)				
1990-2000	-0.02 (0.02)	-0.05 (0.03)	0.03 (0.04)	-1.79 (14.59)				
1960-2000	0.31 (0.02)	0.00 (0.03)	0.31 (0.05)	1.01 (0.10)				

Notes: See the notes for Table 3.

Table 11: Trends in Keyword Frequencies

	A. Information Content				B. Face-to-Face			
	Total	Between	Within	Within Share	Total	Between	Within	Within Share
1960 Level	3.04 (0.06)				7.65 (0.11)			
1960-1970	0.66 (0.06)	0.06 (0.01)	0.60 (0.06)	0.91 (0.01)	1.24 (0.13)	0.17 (0.01)	1.07 (0.13)	0.86 (0.02)
1970-1980	1.10 (0.04)	0.04 (0.01)	1.07 (0.04)	0.97 (0.01)	1.75 (0.10)	0.60 (0.02)	1.15 (0.09)	0.66 (0.02)
1980-1990	1.40 (0.04)	-0.13 (0.03)	1.53 (0.06)	1.09 (0.02)	0.54 (0.10)	0.44 (0.05)	0.10 (0.11)	0.18 (0.10)
1990-2000	1.07 (0.09)	0.02 (0.12)	1.05 (0.18)	0.98 (0.11)	1.20 (0.23)	-0.25 (0.26)	1.45 (0.36)	1.21 (0.21)
1960-2000	4.24 (0.11)	-0.01 (0.14)	4.25 (0.20)	1.00 (0.03)	4.72 (0.27)	0.96 (0.29)	3.76 (0.45)	0.80 (0.06)
	C. On-Site Job				D. Decision-Making			
1960 Level	17.28 (0.25)				2.16 (0.06)			
1960-1970	-1.32 (0.27)	-0.27 (0.02)	-1.04 (0.27)	0.79 (0.04)	0.32 (0.06)	0.13 (0.01)	0.18 (0.06)	0.58 (0.09)
1970-1980	-1.83 (0.14)	-0.71 (0.04)	-1.12 (0.16)	0.61 (0.04)	0.62 (0.03)	0.23 (0.01)	0.38 (0.04)	0.62 (0.03)
1980-1990	-3.78 (0.11)	-0.17 (0.06)	-3.61 (0.15)	0.95 (0.02)	0.72 (0.04)	0.16 (0.02)	0.56 (0.05)	0.78 (0.03)
1990-2000	-2.37 (0.25)	0.03 (0.24)	-2.40 (0.41)	1.01 (0.10)	1.08 (0.11)	-0.16 (0.18)	1.24 (0.23)	1.15 (0.15)
1960-2000	-9.30 (0.34)	-1.13 (0.26)	-8.17 (0.51)	0.88 (0.03)	2.73 (0.15)	0.37 (0.19)	2.36 (0.28)	0.87 (0.07)

Notes: See the notes for Table 3.

Table 12: Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	A. Nonroutine Analytic				B. Nonroutine Interactive			
1960 Level	2.01 (0.05)				1.72 (0.03)			
1960-1970	0.10 (0.04)	0.06 (0.01)	0.03 (0.04)	0.34 (7.82)	-0.17 (0.03)	0.08 (0.00)	-0.25 (0.03)	1.49 (0.10)
1970-1980	0.08 (0.02)	0.07 (0.01)	0.01 (0.02)	0.10 (0.48)	0.17 (0.01)	0.07 (0.01)	0.10 (0.01)	0.60 (0.04)
1980-1990	0.20 (0.02)	0.04 (0.01)	0.15 (0.02)	0.78 (0.06)	0.34 (0.02)	0.03 (0.01)	0.31 (0.02)	0.92 (0.03)
1990-2000	0.34 (0.07)	-0.16 (0.09)	0.50 (0.12)	1.45 (0.27)	0.23 (0.06)	-0.02 (0.05)	0.25 (0.09)	1.07 (0.18)
1960-2000	0.72 (0.09)	0.02 (0.10)	0.70 (0.15)	0.97 (0.13)	0.58 (0.08)	0.16 (0.05)	0.42 (0.11)	0.73 (0.10)
	C. Nonroutine Manual				D. Routine Cognitive			
1960 Level	0.30 (0.01)				0.23 (0.01)			
1960-1970	0.07 (0.01)	0.00 (0.00)	0.07 (0.01)	0.99 (0.03)	-0.06 (0.01)	0.01 (0.00)	-0.07 (0.01)	1.16 (0.04)
1970-1980	0.01 (0.01)	-0.04 (0.00)	0.06 (0.01)	4.44 (1.63)	-0.03 (0.00)	-0.01 (0.00)	-0.03 (0.00)	0.82 (0.04)
1980-1990	-0.06 (0.01)	0.01 (0.01)	-0.07 (0.01)	1.18 (0.14)	-0.03 (0.00)	-0.01 (0.00)	-0.02 (0.01)	0.64 (0.11)
1990-2000	0.01 (0.03)	0.02 (0.03)	-0.01 (0.05)	-1.06 (8.93)	-0.04 (0.01)	-0.01 (0.01)	-0.03 (0.01)	0.88 (0.18)
1960-2000	0.03 (0.04)	-0.01 (0.03)	0.05 (0.06)	1.40 (2.48)	-0.17 (0.01)	-0.01 (0.01)	-0.15 (0.01)	0.92 (0.05)
	E. Routine Manual							
1960 Level	0.22 (0.01)							
1960-1970	-0.04 (0.01)	-0.01 (0.00)	-0.03 (0.01)	0.69 (0.10)				
1970-1980	-0.06 (0.00)	-0.02 (0.00)	-0.04 (0.01)	0.70 (0.04)				
1980-1990	-0.08 (0.00)	0.01 (0.00)	-0.10 (0.01)	1.17 (0.04)				
1990-2000	-0.04 (0.00)	0.01 (0.00)	-0.04 (0.01)	1.25 (0.09)				
1960-2000	-0.21 (0.01)	-0.01 (0.00)	-0.21 (0.01)	0.97 (0.02)				

Notes: See the notes for Table 3. In Table 3, we include not only the words mentioned in footnote 11, but also similar words according to our continuous bag of words model. Here, instead, we apply only the mapping between task groups and words mentioned in footnote 11.

In Table 3, in the body of the paper, we applied a 4-digit SOC classification. In Tables 13 and 14, we recompute these trends with narrower occupation classification schemes. In Table 13, we apply a 6-digit SOC classification, while in Table 14 we categorize ads according to their job titles (as opposed to grouping job titles by SOC codes). The classification used in Table 14 is the finest classification one could possibly apply when decomposing trends in keyword frequencies in between-occupation and within-occupation components. As one would expect, with a finer occupation classification scheme, the share of changes in keyword frequencies that are due to the within-occupation component are somewhat lower. However, even here, for each of the task measures, a majority of the changes in task content occur within occupations.

Finally, a possible limitation is that we are using job ads (which capture the task content of newly formed jobs) to measure stock of jobs existing at that point in time. Underlying our results is the assumption that job ads reflect the task content of all jobs within the occupation (both new and existing). Here, we make the opposite assumption, namely that once a job is formed its task content is fixed over time. With this assumption, and with knowledge of the rate at which jobs turn over within an occupation (call this ς_j), we can compute the evolution of the task content of the stock (\check{T}_{jt}) of a given task in occupation j using a perpetual inventory method:

$$\check{T}_{jt} = \tilde{T}_{jt} \cdot \varsigma_j + \check{T}_{jt-1} \cdot (1 - \varsigma_j), \quad (13)$$

initializing $\check{T}_{jt} = \tilde{T}_{jt}$ for $t = 1960$. In this equation \tilde{T}_{jt} , equals a measure of the task content of occupation j in job ads at time t . To measure the job turn over rate, we take the sample (within the CPS-ASEC) of employed workers.⁵¹ For workers employed in occupation j , we compute the turn over rate as the fraction of workers who were either in a different occupation in the previous year or who had more than one employer. Once we have computed \check{T}_{jt} , we recompute the overall and within-occupation changes in tasks in Table 15. The results from this table are that i) the overall shifts in tasks are smaller than in the benchmark specification, and ii) the “Within Share” is slightly smaller than in the benchmark specification, yet still above three-quarters for the four tasks for which there are trends in the overall task measure.

D.6 Plots of Task Measures within Occupations

In this appendix, we first present a third vignette of occupational change, that of office clerical work. We then plot changes in the frequencies of different task words within the three clusters of occupations: the two that were the focus of Section 4.2, and the third which we have introduced here. The goal of this appendix is to demonstrate that the trends which we had plotted in Section 4.2 reflect changes within 4-digit SOC occupations — as opposed

⁵¹We restrict attention to workers who are between the age of 16 and 65, who work at least 40 weeks in the previous year, who have non-allocated information on age, race, gender, occupation, and number employers.

Table 13: Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	A. Nonroutine Analytic				B. Nonroutine Interactive			
1960 Level	3.44 (0.10)				4.96 (0.08)			
1960-1970	0.21 (0.14)	0.09 (0.04)	0.12 (0.15)	0.56 (1.65)	-0.23 (0.10)	0.06 (0.04)	-0.29 (0.11)	1.28 (9.01)
1970-1980	0.57 (0.18)	0.22 (0.07)	0.36 (0.19)	0.62 (0.07)	0.84 (0.09)	0.34 (0.07)	0.50 (0.12)	0.59 (0.08)
1980-1990	0.63 (0.27)	0.42 (0.15)	0.21 (0.26)	0.33 (0.30)	0.77 (0.17)	0.35 (0.21)	0.41 (0.27)	0.54 (0.15)
1990-2000	0.88 (0.26)	-0.17 (0.32)	1.05 (0.34)	1.19 (4.18)	0.57 (0.26)	-0.13 (0.30)	0.69 (0.34)	1.22 (9.29)
1960-2000	2.28 (0.16)	0.56 (0.26)	1.72 (0.32)	0.75 (0.12)	1.95 (0.20)	0.63 (0.28)	1.31 (0.30)	0.67 (0.12)
	C. Nonroutine Manual				D. Routine Cognitive			
1960 Level	1.00 (0.05)				1.24 (0.03)			
1960-1970	0.02 (0.06)	0.04 (0.02)	-0.02 (0.06)	-0.90 (0.18)	-0.26 (0.04)	0.01 (0.01)	-0.27 (0.04)	1.05 (0.04)
1970-1980	-0.01 (0.05)	-0.09 (0.04)	0.08 (0.06)	-6.17 (0.20)	-0.14 (0.04)	-0.02 (0.02)	-0.12 (0.04)	0.87 (0.80)
1980-1990	-0.03 (0.10)	0.01 (0.27)	-0.04 (0.29)	1.49 (1.93)	-0.07 (0.08)	0.03 (0.08)	-0.10 (0.10)	1.51 (6.75)
1990-2000	-0.07 (0.11)	0.02 (0.27)	-0.08 (0.28)	1.22 (6.62)	-0.01 (0.11)	-0.03 (0.09)	0.02 (0.14)	-1.13 (0.38)
1960-2000	-0.09 (0.08)	-0.03 (0.08)	-0.06 (0.10)	0.71 (8.52)	-0.48 (0.06)	0.00 (0.06)	-0.48 (0.08)	1.00 (0.10)
	E. Routine Manual							
1960 Level	0.78 (0.03)							
1960-1970	-0.21 (0.03)	-0.04 (0.01)	-0.17 (0.04)	0.80 (0.06)				
1970-1980	-0.20 (0.04)	-0.05 (0.04)	-0.15 (0.07)	0.76 (0.74)				
1980-1990	-0.17 (0.06)	-0.04 (0.07)	-0.13 (0.13)	0.77 (0.25)				
1990-2000	-0.08 (0.05)	0.03 (0.07)	-0.11 (0.11)	1.40 (1.55)				
1960-2000	-0.66 (0.04)	-0.10 (0.03)	-0.56 (0.05)	0.85 (0.05)				

Notes: See the notes for Table 3. In comparison we here apply an occupation classification scheme based on 6-digit SOC codes, as opposed to 4-digit SOC codes.

Table 14: Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	A. Nonroutine Analytic				B. Nonroutine Interactive			
1960 Level	4.15				5.39			
1960-1970	-0.31	-0.33	0.03	-0.08	-0.22	0.16	-0.38	1.75
1970-1980	0.77	0.44	0.33	0.43	0.53	0.07	0.46	0.88
1980-1990	0.80	0.43	0.38	0.47	1.08	0.68	0.40	0.37
1990-2000	0.74	0.24	0.50	0.67	1.28	0.61	0.67	0.52
1960-2000	2.01	0.78	1.24	0.61	2.68	1.52	1.16	0.43
	C. Nonroutine Manual				D. Routine Cognitive			
1960 Level	0.60				1.78			
1960-1970	-0.08	-0.06	-0.02	0.30	-0.27	0.06	-0.33	1.22
1970-1980	0.10	0.09	0.01	0.14	-0.27	-0.17	-0.10	0.37
1980-1990	0.01	-0.02	0.03	2.29	-0.24	-0.38	0.14	-0.59
1990-2000	-0.05	-0.03	-0.03	0.54	-0.17	0.18	-0.36	2.05
1960-2000	-0.02	-0.01	-0.01	0.42	-0.95	-0.30	-0.65	0.68
	E. Routine Manual							
1960 Level	0.49							
1960-1970	-0.21	-0.06	-0.15	0.70				
1970-1980	-0.08	0.03	-0.11	1.44				
1980-1990	-0.08	-0.03	-0.05	0.64				
1990-2000	-0.07	-0.01	-0.06	0.80				
1960-2000	-0.44	-0.07	-0.37	0.83				

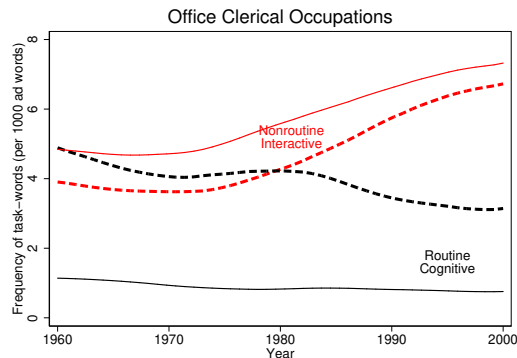
Notes: See the notes for Table 3. In comparison, we here apply an occupation classification scheme based on job titles, as opposed to 4-digit SOC codes.

Table 15: Trends in Keyword Frequencies

	Total	Between	Within	Within Share	Total	Between	Within	Within Share
	A. Nonroutine Analytic				B. Nonroutine Interactive			
1960 Level	3.22 (0.08)				4.68 (0.05)			
1960-1970	0.30 (0.07)	0.13 (0.01)	0.17 (0.07)	0.58 (0.23)	0.07 (0.05)	0.14 (0.01)	-0.08 (0.05)	-1.12 (0.93)
1970-1980	0.48 (0.04)	0.19 (0.01)	0.29 (0.04)	0.61 (0.04)	0.56 (0.03)	0.30 (0.01)	0.26 (0.03)	0.47 (0.01)
1980-1990	0.67 (0.04)	0.17 (0.02)	0.50 (0.04)	0.74 (0.03)	0.83 (0.04)	0.13 (0.02)	0.70 (0.05)	0.84 (0.02)
1990-2000	0.79 (0.11)	-0.15 (0.15)	0.94 (0.20)	1.19 (0.13)	0.86 (0.12)	-0.08 (0.15)	0.94 (0.24)	1.09 (0.15)
1960-2000	2.24 (0.14)	0.33 (0.15)	1.90 (0.23)	0.85 (0.06)	2.32 (0.15)	0.49 (0.16)	1.82 (0.27)	0.79 (0.06)
	C. Nonroutine Manual				D. Routine Cognitive			
1960 Level	0.84 (0.03)				1.25 (0.02)			
1960-1970	0.13 (0.02)	0.03 (0.00)	0.10 (0.03)	0.76 (1.56)	-0.17 (0.02)	0.04 (0.00)	-0.21 (0.02)	1.23 (0.02)
1970-1980	-0.02 (0.01)	-0.11 (0.01)	0.09 (0.01)	-5.70 (0.60)	-0.17 (0.01)	0.00 (0.00)	-0.17 (0.01)	0.99 (0.02)
1980-1990	-0.03 (0.02)	-0.04 (0.01)	0.01 (0.02)	-0.46 (0.14)	-0.08 (0.01)	-0.03 (0.01)	-0.05 (0.02)	0.60 (0.54)
1990-2000	-0.08 (0.04)	-0.03 (0.03)	-0.05 (0.05)	0.63 (5.21)	-0.06 (0.06)	-0.07 (0.14)	0.01 (0.20)	-0.18 (18.44)
1960-2000	0.01 (0.06)	-0.14 (0.04)	0.16 (0.07)	11.96 (0.90)	-0.48 (0.06)	-0.07 (0.15)	-0.42 (0.20)	0.86 (0.41)
	E. Routine Manual							
1960 Level	0.72 (0.03)							
1960-1970	-0.10 (0.03)	-0.02 (0.00)	-0.08 (0.03)	0.81 (0.03)				
1970-1980	-0.18 (0.01)	-0.07 (0.00)	-0.12 (0.01)	0.63 (0.02)				
1980-1990	-0.19 (0.01)	-0.01 (0.01)	-0.19 (0.01)	0.97 (0.04)				
1990-2000	-0.14 (0.02)	0.05 (0.02)	-0.19 (0.01)	1.38 (0.37)				
1960-2000	-0.61 (0.03)	-0.04 (0.02)	-0.57 (0.03)	0.93 (0.03)				

Notes: See the notes for Table 3. In comparison, we here apply Equation 13 to impute occupations' task measures.

Figure 22: Task Measures: Office Clerical Occupations



Notes: We apply a local polynomial smoother. In this figure, office clerical occupations (with a SOC code between 4330 and 4341) are plotted as dashed lines.

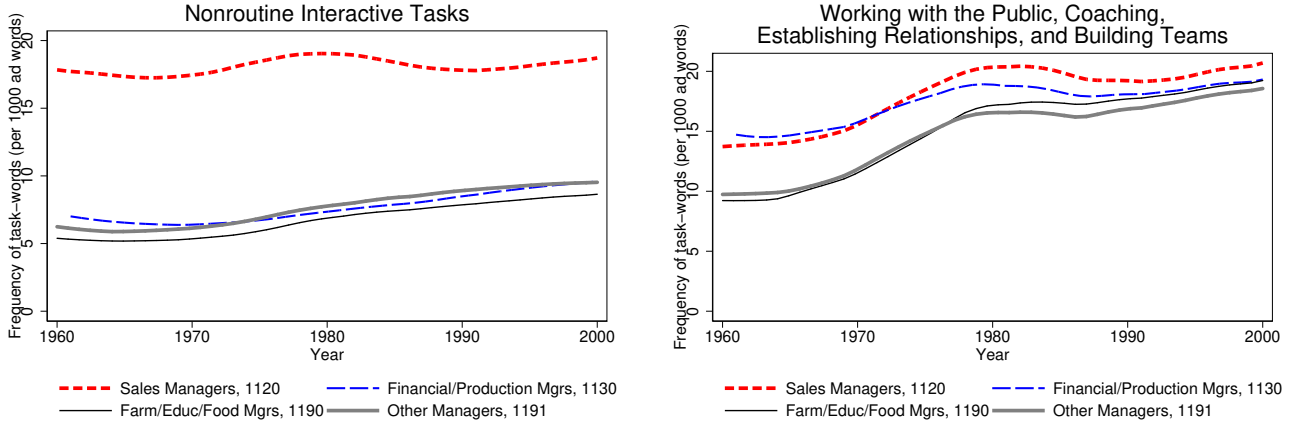
to changes between 4-digit occupations — within these clusters of occupations.

In Figure 22, we contrast trends in task measures for office clerks compared to all occupations. While mentions of routine cognitive tasks has decreased for both office clerks and more generally for all occupations, the drop off has been more pronounced in clerical positions. Concurrently, the frequency of nonroutine interactive task-related words has increased in clerical ads roughly at the same pace as in other occupations. Both trends are consistent with Autor (2015)’s account of changes experienced by bank tellers (one particular office clerk occupation). He writes: “Increasingly, banks recognized the value of tellers enabled by information technology, not primarily as checkout clerks, but as salespersons, forging relationships with customers and introducing them to additional bank services like credit cards, loans, and investment products.” (p. 7) Hence, much of the overall decline in routine cognitive tasks occurred in occupations like clerical occupations that were previously specialized in these tasks. The remaining jobs in these occupations increasingly contain nonroutine analytic and interactive tasks.

In Figure 23, we plot changes in the frequencies of nonroutine interactive tasks (left panel) and the interpersonal activities that were mentioned in the [National Research Council \(1999\)](#) report (right panel). For Sales Managers, an occupation in which nonroutine interactive tasks are related to selling, the increase in nonroutine tasks is modest, from 17.7 to 18.2 mentions per thousand ad words. For other managerial occupations, nonroutine interactive tasks increase more quickly, from 7.8 to 9.7 mentions for Top Executives; from 7.1 to 9.5 mentions for Financial, Purchasing, and Production Managers; from 5.7 to 8.0 for Farm, Education; and Food Managers, and from 7.1 to 8.7 for Other Managers. Across all managerial occupations, there has been an exceptionally large increase in mentions of working with the public, coaching, establishing relationships, and building teams.

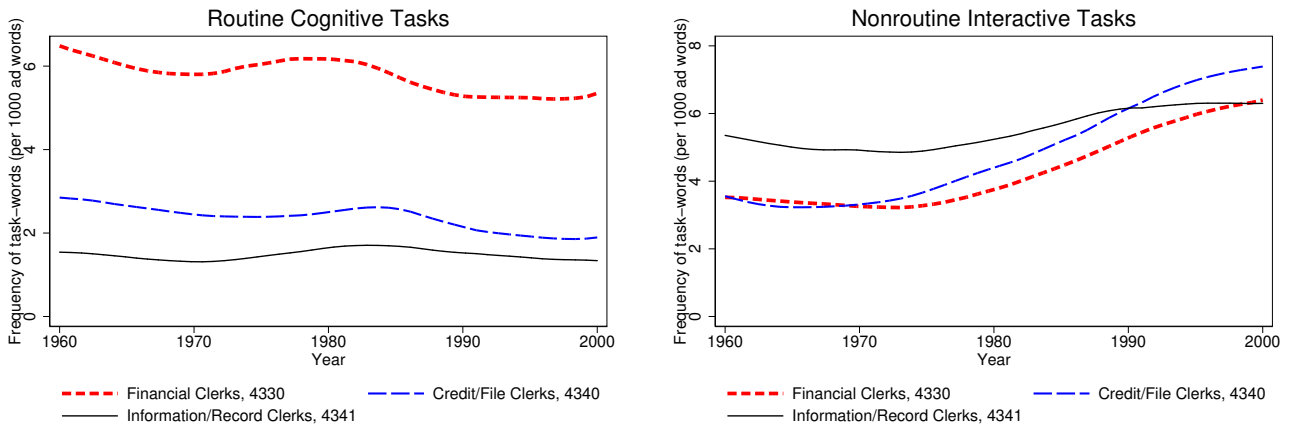
In Figure 24, we plot trends in routine cognitive tasks (left panel) and nonroutine interactive tasks (right panel) for three office clerical occupations. Within each of the three

Figure 23: Task Measures: Managerial Occupations



Notes: We apply a local polynomial smoother.

Figure 24: Task Measures: Office Clerical Occupations

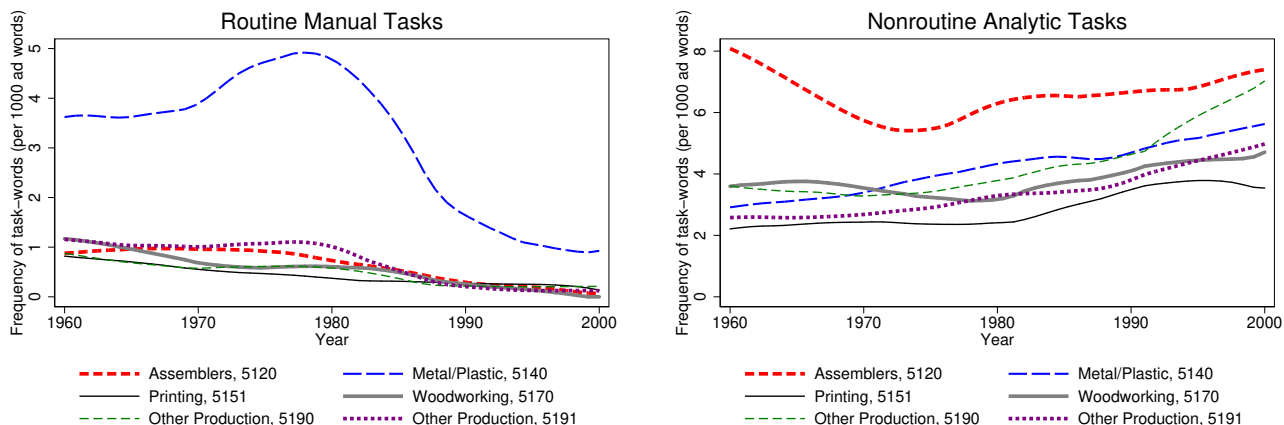


Notes: We apply a local polynomial smoother.

occupations, routine cognitive tasks have been mentioned in job ads less and less frequently over time; the largest decrease has occurred for Information and Record Clerks. On the other hand, mentions of nonroutine interactive tasks have increased considerably for all three occupations, especially so for Credit/File Clerks.

Finally, Figure 25 presents the changes in routine manual tasks and nonroutine analytic tasks for six separate production worker occupations. Across all six occupations, the frequency of routine manual words has declined dramatically: from 0.9 to 0.1 mentions per thousand words for Assemblers; from 3.6 to 0.9 mentions for Metal and Plastic production workers; from 0.7 to 0.2 mentions for Printing workers; from 0.7 to 0.4 mentions for Woodworking workers; from 0.5 to 0.3 for Other Production (SOC=5190) worker; and 1.0 to 0.1 for Other Production (SOC=5191) workers. With the exception of the “Assemblers” occupa-

Figure 25: Task Measures: Non-Supervisory Production Occupations



Notes: We apply a local polynomial smoother.

tion, the frequency of words related to nonroutine analytic tasks in job ads for each of these occupations has increased.

In summary, Figures 23 to 25 demonstrate that our narratives from Section 4.2 describe within-occupation changes in task content. Again, these changes would be difficult to detect using previous, conventional data sets.

E Sensitivity Analysis and Supplemental Figures and Tables Related to Section 5.1

E.1 RIF Regression Results

In this appendix, we present supplemental tables and figures related to our wage distribution decompositions in Section 5.1. Tables 16 and 17 give results from the RIF regressions of male workers' log wage income in 1960, 1980, and 2000 (we omitted the results from 1970 and 1990 so as to fit each table on a single page). These RIF regressions correspond to the decompositions plotted in Figure 5 and 7 in Section 5.1. In Table 16, the task measures freely vary throughout the sample period, while in Table 17 occupations' task measures are fixed at their sample means.

E.2 Decompositions with Alternate Measures, Samples

In this appendix, we present the wage structure effects of the decompositions we introduced in Section 5.1. We then begin to explore the sensitivity of our Section 5.1 results to our specification of tasks in our RIF regressions and to the sample.

In Figure 26, we present the analogue of Figures 5 and 6, plotting the wage structure

Table 16: RIF Regression Coefficients on Male Log Earnings, [Spitz-Oener \(2006\)](#) Task Measures

Year	1960		1980		2000	
	10	90	10	90	10	90
Quantile						
Non white	-0.441 (0.004)	-0.090 (0.001)	-0.184 (0.004)	-0.080 (0.001)	-0.082 (0.004)	-0.092 (0.002)
Not married	-0.605 (0.003)	-0.086 (0.001)	-0.644 (0.003)	-0.056 (0.001)	-0.511 (0.003)	-0.134 (0.002)
Experience<10	-0.522 (0.003)	-0.408 (0.002)	-0.585 (0.003)	-0.349 (0.002)	-0.954 (0.004)	-0.297 (0.002)
10≤Experience<20	-0.027 (0.002)	-0.132 (0.002)	-0.045 (0.002)	-0.156 (0.002)	-0.050 (0.003)	-0.093 (0.002)
Experience≥30	-0.012 (0.002)	-0.006 (0.002)	0.044 (0.003)	-0.030 (0.002)	-0.046 (0.003)	0.014 (0.003)
Some High School	-0.204 (0.003)	-0.302 (0.003)	-0.473 (0.004)	-0.152 (0.001)	-0.804 (0.006)	-0.064 (0.002)
High School	0.009 (0.002)	-0.168 (0.003)	0.048 (0.003)	-0.068 (0.001)	-0.023 (0.003)	-0.069 (0.001)
College	0.135 (0.003)	0.446 (0.005)	0.265 (0.003)	0.279 (0.002)	0.309 (0.003)	0.461 (0.003)
Post-grad	0.089 (0.004)	0.600 (0.006)	0.226 (0.003)	0.430 (0.003)	0.257 (0.004)	1.025 (0.004)
Nonroutine Analytic	0.006 (0.001)	0.153 (0.001)	0.065 (0.001)	0.043 (0.001)	0.101 (0.001)	0.042 (0.001)
Nonroutine Interactive	-0.002 (0.001)	0.220 (0.001)	0.016 (0.001)	0.094 (0.001)	0.012 (0.001)	0.136 (0.001)
Routine Cognitive	0.016 (0.001)	-0.012 (0.001)	0.033 (0.002)	-0.025 (0.001)	0.027 (0.002)	-0.015 (0.001)
Routine Manual	0.065 (0.001)	0.004 (0.001)	0.065 (0.001)	-0.001 (0.000)	0.006 (0.005)	0.019 (0.001)
Nonroutine Manual	-0.076 (0.001)	-0.008 (0.001)	0.003 (0.001)	0.004 (0.000)	0.092 (0.002)	-0.016 (0.001)
Constant	9.687 (0.002)	11.195 (0.003)	9.970 (0.003)	11.306 (0.002)	10.091 (0.004)	11.385 (0.002)
N	1427801	1427801	1846332	1846332	2230601	2230601
Adjusted R^2	0.162	0.192	0.127	0.149	0.131	0.168

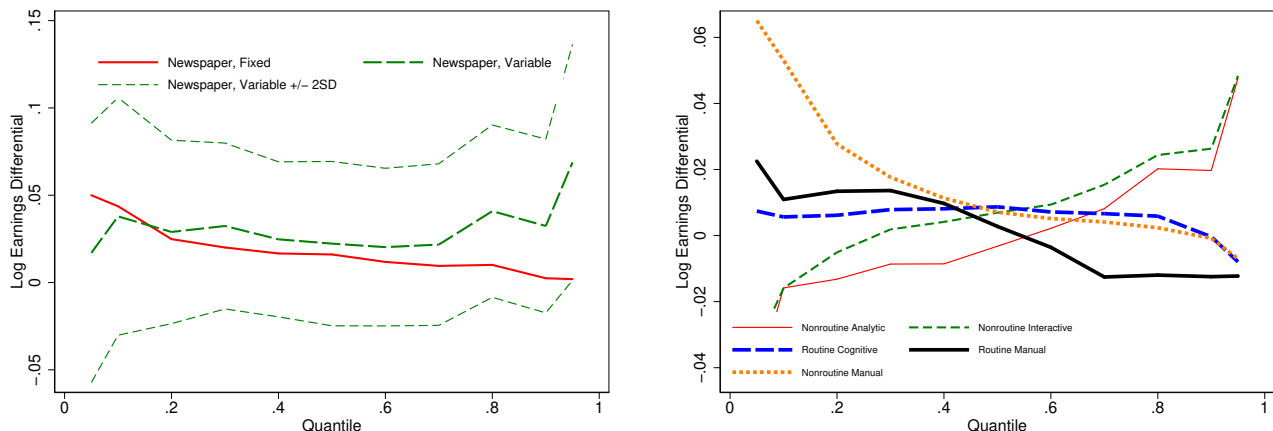
Notes: The table contains coefficients and standard errors from RIF regressions. The task measures are computed using data from the *Boston Globe*, *New York Times*, and *Wall Street Journal*, with keyword frequencies computed on a year-by-year basis and then smoothed using a locally weighted polynomial regression. Each of the five task measures are normalized to have mean 0 and standard deviation 1, averaged over all individuals in the regression sample.

Table 17: RIF Regression Coefficients on Male Log Earnings, [Spitz-Oener \(2006\)](#) Task Measures

Year	1960		1980		2000	
Quantile	10	90	10	90	10	90
Non white	-0.446 (0.004)	-0.099 (0.001)	-0.182 (0.004)	-0.079 (0.001)	-0.069 (0.004)	-0.086 (0.002)
Not married	-0.608 (0.003)	-0.086 (0.001)	-0.643 (0.003)	-0.055 (0.001)	-0.499 (0.003)	-0.130 (0.002)
Experience<10	-0.527 (0.003)	-0.403 (0.002)	-0.586 (0.003)	-0.348 (0.002)	-0.942 (0.004)	-0.296 (0.002)
10≤Experience<20	-0.029 (0.002)	-0.130 (0.002)	-0.045 (0.002)	-0.156 (0.002)	-0.047 (0.003)	-0.094 (0.002)
Experience≥30	-0.012 (0.002)	-0.010 (0.002)	0.045 (0.003)	-0.030 (0.002)	-0.045 (0.003)	0.015 (0.003)
Some High School	-0.202 (0.003)	-0.293 (0.003)	-0.477 (0.004)	-0.151 (0.001)	-0.792 (0.006)	-0.061 (0.002)
High School	0.010 (0.002)	-0.160 (0.003)	0.045 (0.003)	-0.068 (0.001)	-0.026 (0.003)	-0.065 (0.001)
College	0.136 (0.003)	0.424 (0.005)	0.267 (0.003)	0.279 (0.002)	0.311 (0.003)	0.441 (0.003)
Post-grad	0.097 (0.004)	0.523 (0.006)	0.227 (0.003)	0.433 (0.003)	0.274 (0.004)	1.003 (0.004)
Nonroutine Analytic	0.009 (0.001)	0.147 (0.001)	0.058 (0.001)	0.042 (0.001)	0.116 (0.001)	0.047 (0.001)
Nonroutine Interactive	-0.006 (0.001)	0.143 (0.001)	0.024 (0.001)	0.096 (0.001)	0.034 (0.001)	0.167 (0.001)
Routine Cognitive	0.032 (0.001)	-0.019 (0.001)	0.024 (0.002)	-0.023 (0.001)	0.048 (0.003)	-0.034 (0.001)
Routine Manual	0.051 (0.000)	-0.006 (0.000)	0.067 (0.001)	0.001 (0.000)	0.081 (0.001)	-0.006 (0.001)
Nonroutine Manual	-0.053 (0.001)	0.001 (0.001)	0.002 (0.001)	0.004 (0.000)	0.084 (0.001)	0.000 (0.001)
Constant	9.739 (0.002)	11.085 (0.003)	9.954 (0.003)	11.286 (0.002)	10.117 (0.003)	11.446 (0.002)
N	1427801	1427801	1846332	1846332	2230601	2230601
Adjusted R^2	0.161	0.187	0.127	0.150	0.136	0.173

Notes: The table contains coefficients and standard errors from RIF regressions. The task measures are computed using data from the *Boston Globe*, *New York Times*, and *Wall Street Journal*, with keyword frequencies computed as averages over the 1960-2000 period. Each of the five task measures are normalized to have mean 0 and standard deviation 1, averaged over all individuals in the regression sample.

Figure 26: Decomposition of Real Log Earnings: Wage Structure Effects



Notes: The left panel describes the contribution of occupational characteristics through wage structure effects, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks. In the right panel, we present the corresponding detailed decomposition, using the task measures which are allowed to vary freely over the sample period.

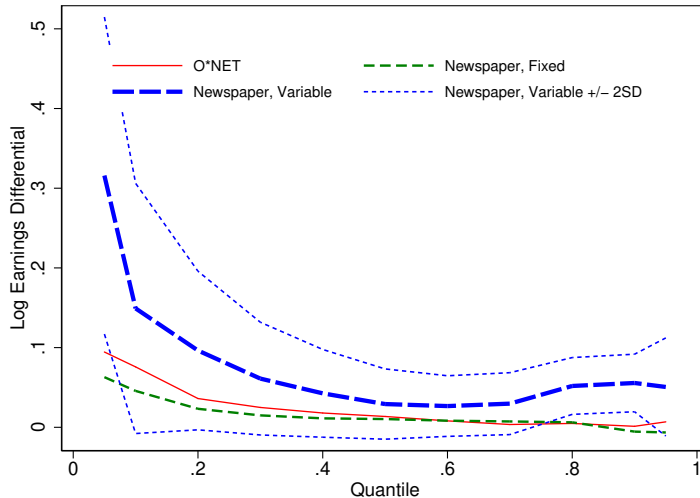
effects as opposed to the composition effects. As a reminder, the wage structure effects aim to capture changes in the earnings distribution which arise via changes in the regression coefficients across time. We chose to emphasize the composition effects over the wage structure effects, as the latter are sensitive to the choice of the omitted group (i.e., for each task measure, the value of that task measure which is the base level of comparison). With that caveat in mind, the left panel of [Figure 26](#) indicates that wage structure effects account for a 1 log point reduction in 90-10 inequality, when using task measures which are allowed to vary within occupations over time, and a 4 log point reduction when using task measures which are fixed for each occupation at their 1960-2000 average. In the right panel, we explore the detailed decomposition effects.

Next, in [Figure 26](#), we plot the wage structure effects in the decompositions which are based on [Firpo, Fortin, and Lemieux \(2014\)](#)'s task measures. Here, wage structure effects account for a 9 point reduction in 90-10 inequality, with a two standard error confidence interval of (-0.24, 0.06).

Overall, [Figures 5 and 6](#) suggest that changes in the RIF coefficients corresponding to our task measures explain a moderate reduction in inequality, and that these changes are similar whether one uses fixed-over-time task measures or task measures which incorporate within-occupation shifts in task content. However, these statements are all subject to substantial statistical uncertainty.

Turning to an exploration of the sensitivity of our statistical decompositions to alternate measures and samples, we begin in [Figure 28](#) by modifying the way in which we measure our groups of nonroutine and routine tasks. In this figure, we search only for the question

Figure 27: Decomposition of Real Log Earnings: Wage Structure Effects



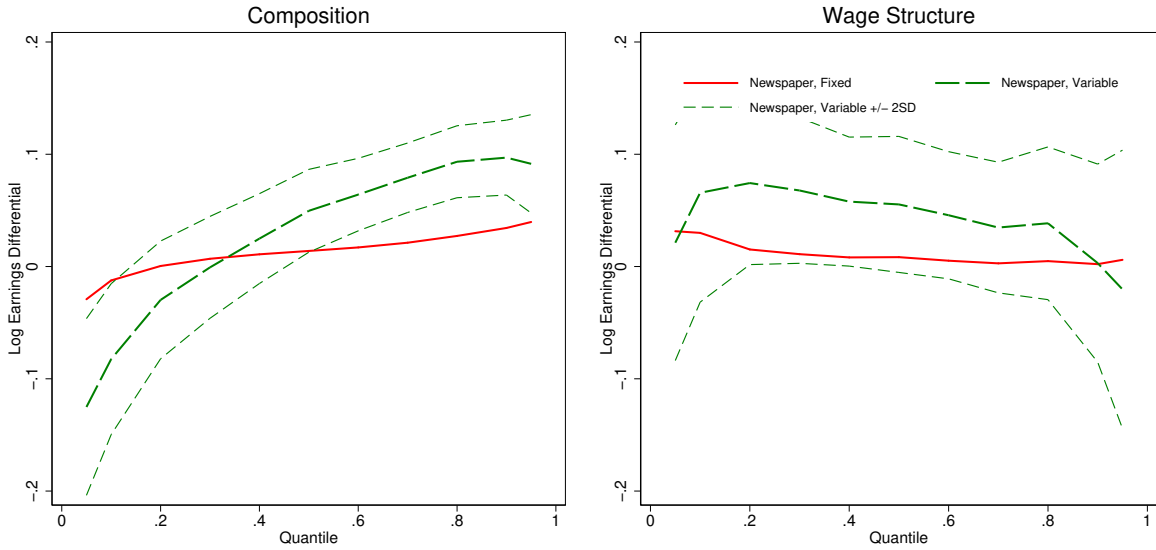
Notes: This figure describes the contribution of occupational characteristics through wage structure effects, using [Firpo, Fortin, and Lemieux \(2014\)](#)'s definitions of routine and nonroutine tasks.

titles in [Spitz-Oener \(2006\)](#)'s original definitions when constructing our task measures. Our measures do not include similar words identified from our continuous bag of words model. Turning to the results, both the wage structure and composition effects account for the difference between Figure 5 and Figure 5 on the one hand and Figure 5. According to the left panel of Figure 28, the composition effects account for a 18 log point increase in 90-10 inequality, slightly smaller than the 22 log point increase reported in the Figure 5. However, the (unobserved) wage structure effects account for a countervailing 6 log point decrease in 90-10 inequality, larger than the 1 log point increase reported in of Figure 5. As in the benchmark specification, changes in task composition of the workforce, as opposed to changes in the return to tasks, are the primary source of the increase in earnings inequality.

Throughout Section 5.1, we transformed the raw newspaper text frequencies using the normalization: $T_{hjt} = (\tilde{T}_{hjt} - \mu_h) / \sigma_h$, where, as a reminder, μ_h is the mean and σ_h is the standard deviation of keyword frequencies for task group h across years and occupations. As a robustness check, in Figure 29 we consider decompositions which are based on an alternate normalization. Instead of subtracting by the mean and dividing by the standard deviation, we instead rank newspaper ads according to the number of mentions of each task: $T_{hjt} = \text{rank}_h \tilde{T}_{hjt}$. This measure ranges between -0.5 (for ads that have the minimum mentions of the given task compared to all other newspaper ads in our newspaper data) to 0.5 (for ads that mention the particular task most frequently). With this alternate definition, the contribution of our task measures to 90-10 inequality is substantially larger — 41 log points versus 22 log points — than in our benchmark specification.

Up to now, our RIF regression-based decompositions included only male workers in our

Figure 28: Decomposition of Real Log Earnings: Specification of Task Measures

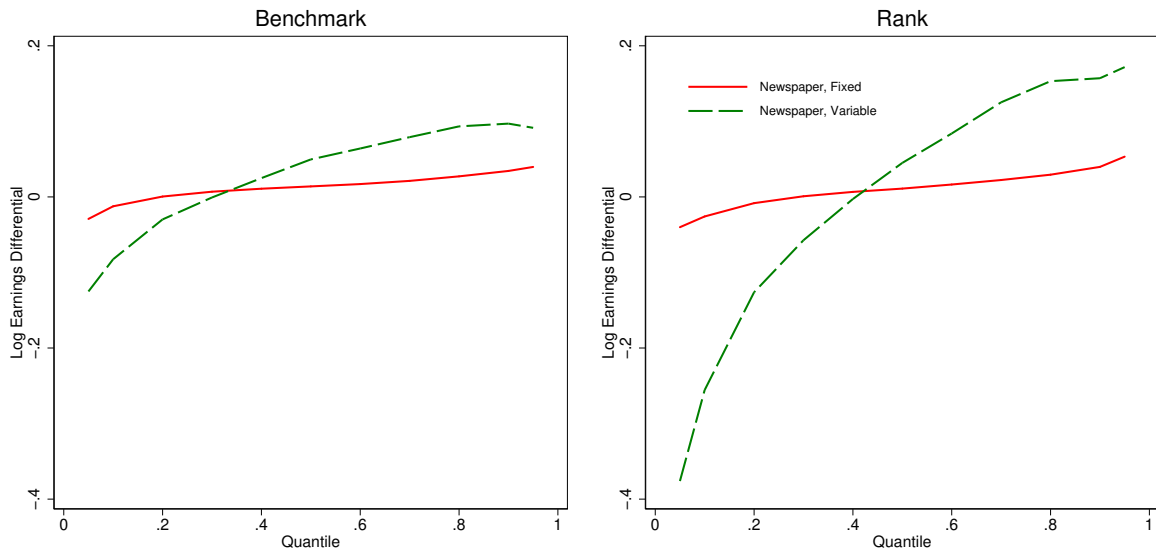


Notes: The left panel describes the contribution of occupational characteristics through compositional changes, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks. The right panel describes the contribution of occupational characteristics through wage structure effects. In [Figure 5](#), we include not only the words mentioned in [footnote 11](#), but also similar words, according to our continuous bag of words model. Here, instead, we apply only the mapping between task groups and question titles used in [Spitz-Oener \(2006\)](#).

samples. We excluded female workers from our sample because of the vast increase in female labor force participation that has occurred since 1960, especially in the 1960s and 1970s. In [Figure 30](#), we recompute our decompositions with both male and female workers (in the left panel) and female workers only (in the right panel). Qualitatively, the results are similar to those given in [Figure 5](#). However, including female workers increases the measured role of our task measures in accounting for the increase in earnings inequality. According to the decomposition plotted in the left panel, [Spitz-Oener \(2006\)](#)'s task measures account for a 29 log point increase in earnings inequality. Performing the same decomposition with a sample of female workers only (right panel), our task measures' composition effects also yield a 28 log point increase in 90-10 earnings inequality.

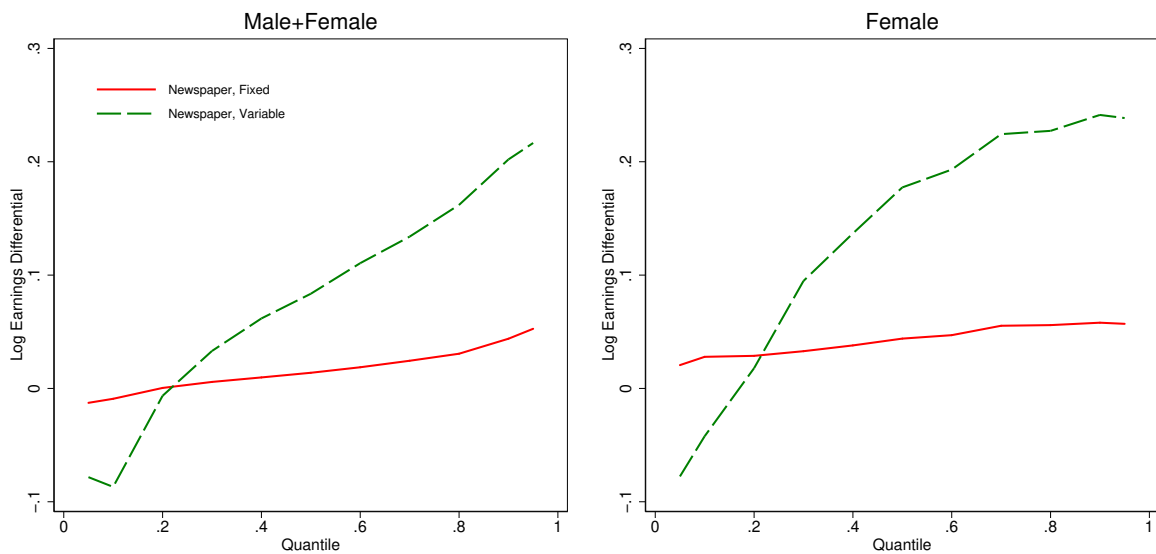
In sum, our benchmark results, given in [Figure 5](#) in [Section 5.1](#), assigned a 22 log point contribution of our task measure to the increase in 90-10 inequality, when looking only at composition effects. In this appendix, we considered three robustness checks: to the way in which our task measures are measured, to the transformation applied to the raw newspaper frequency counts, and to the sample. In the first robustness check, the contribution of our task measures to earnings inequality is somewhat smaller than in our benchmark specification. In the latter two robustness checks, the contribution of our task measures is larger than those reported in [Section 5.1](#). Moreover, as in [Section 5.1](#), incorporating within-occupation,

Figure 29: Decomposition of Real Log Earnings: Specification of Task Measures



Notes: The figure describes the contribution of occupational characteristics through compositional changes, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks.

Figure 30: Decomposition of Real Log Earnings: Male and Female



Notes: The figure describes the contribution of occupational characteristics through compositional changes, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks.

across time shifts in tasks substantially increases the extent to which task shifts account for increasing earnings inequality.

E.3 Decompositions That Use Census Data from Only New York and Boston

As we mentioned in Appendix D.3, our newspaper data contain information almost exclusively about vacancies in the New York City and Boston metro areas, two areas not necessarily representative of the overall U.S. labor market. In this appendix, we re-compute some of our main figures, using only census data on workers from the New York City and Boston metropolitan statistical areas.⁵² As a preview, the main results of this appendix are that i) the relationship between occupations' shares of newspaper vacancy posting counts and their shares of workers in the decennial census is slightly stronger when we restrict our census data to only include individuals residing in the New York and Boston metro areas and that ii) the RIF-based wage decompositions paint a similar picture for the role of technology in accounting for labor income inequality. While we prefer the paper's main sample to include workers throughout the United States, since this choice allows us to make statements about the U.S. wage distribution (an object of greater intrinsic interest than the wage distribution of workers residing in New York City and Boston), because of the discrepancy between the regions covered by the newspaper text and decennial census samples we are admittedly ambivalent about this choice.

Figures 31 and 32 present the share of workers in each occupation in the decennial census and the share of vacancy postings in each occupation in our newspaper data. Again, compared to Figures 10 and 11, the sole difference is that we are looking at workers who in the census are reported as living in either the Boston MSA or the New York MSA. The two data sources now align slightly more closely here, than in Figures 10 and 11. Across 2-digit occupations, the correlation of the shares depicted in Figure 31 are 0.75, 0.91, and 0.73 for 1960, 1980, and 2000, respectively — on average 13 percentage points higher than in comparable years when using census data from the entire U.S. In Figure 32, the correlations among occupations' newspaper vacancy postings and occupations New York and Boston worker shares at the 4-digit level are 0.24, 0.54, 0.52, and 0.40 for 1960, 1970, 1980, and 2000, respectively.

Next, we examine whether the wage decompositions differ when using only census data from the New York and Boston metro areas. Within the New York and Boston metro areas, overall labor earnings inequality increased more rapidly than in the U.S. overall. Between 1960 and 2000, the 90-10 difference of log earnings increased by 75 log points; the 50-10 difference of log earnings increased by 43 log points. While the increase in inequality is greater in Boston and New York City than in the country as a whole, Spitz-Oener (2006)'s measures explain a 13 log point increase (with a two standard error confidence interval of

⁵²To ensure that the boundaries of the MSAs are fixed through time, we remove individuals who reside in counties which were added to the New York MSA definitions part of the way through our sample period: Hunterdon County, Middlesex County, Somerset County, Sussex County, and Warren County. All five of these counties are in New Jersey.

Figure 31: Occupation Shares

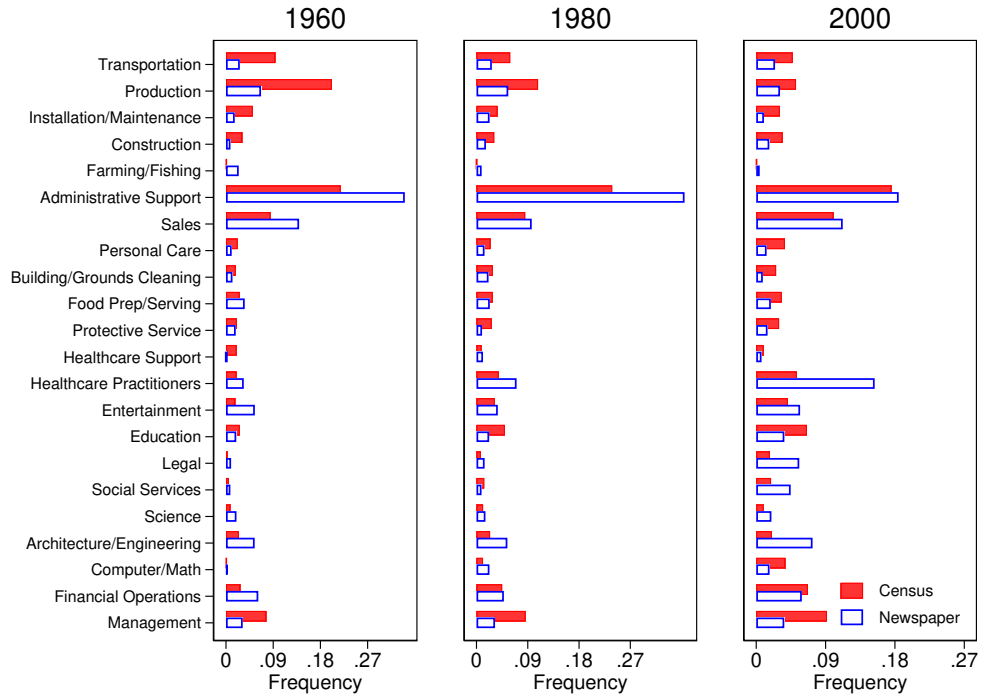


Figure 32: Occupation Shares

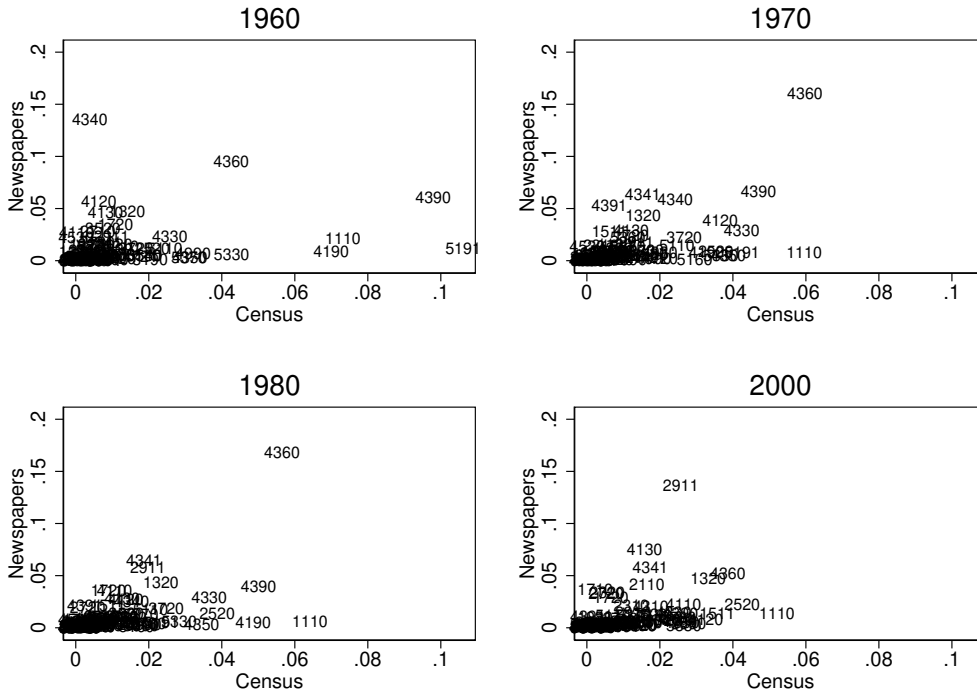
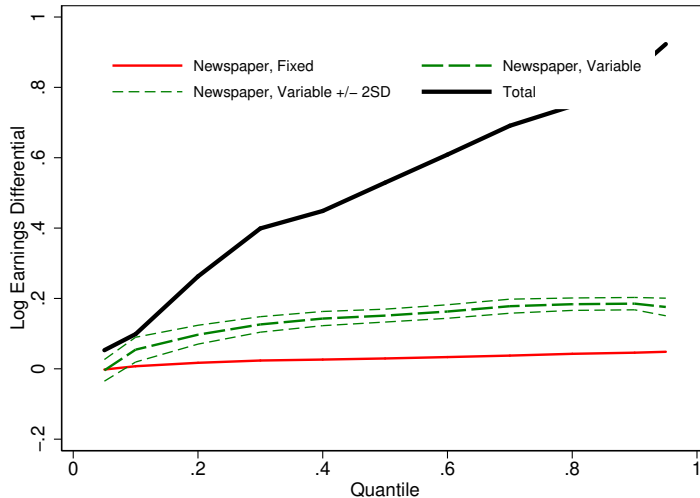


Figure 33: Detailed Decompositions: Boston and New York MSA Data



Notes: The figure describes the contribution of occupational characteristics through both compositional changes, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks. The individual components of the composition effects can be found in [Figure 35](#).

0.09 to 0.16) in 90-10 earning inequality, somewhat smaller than the 22 log point value we reported in [Section 5.1](#).

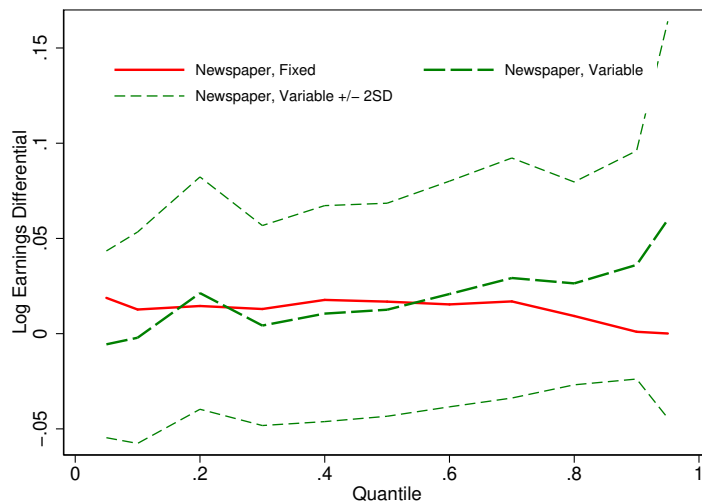
In [Figure 34](#), we plot the wage structure effects. The task measures, through changes in task prices, account for essentially none of the increase in 90-10 inequality, consistent with our benchmark results.

The detailed decomposition ([Figure 35](#)) indicates that changes in the composition of jobs, as measured by their nonroutine interactive and routine manual task measures account for a 14 log point and 5 log point increase in 90-10 inequality. The contribution of nonroutine analytic tasks, through wage structure effects, explain a 6 log point increase in 90-10 inequality, with most of this effect occurring in the top half of the earnings distribution. Nonroutine analytic tasks, through composition effects, explain a countervailing 9 log point decrease in 90-10 inequality.

In [Figure 36](#), we present the change in the distribution of earnings between 1960 and 2000, and the changes which are due to technological progress and offshoring, according to the [Firpo, Fortin, and Lemieux \(2014\)](#) categorization of O*NET Elements. The task measures, here, contribute a 12 log point increase in 90-10 inequality; the two standard error confidence interval spans 0.07 to 0.17.

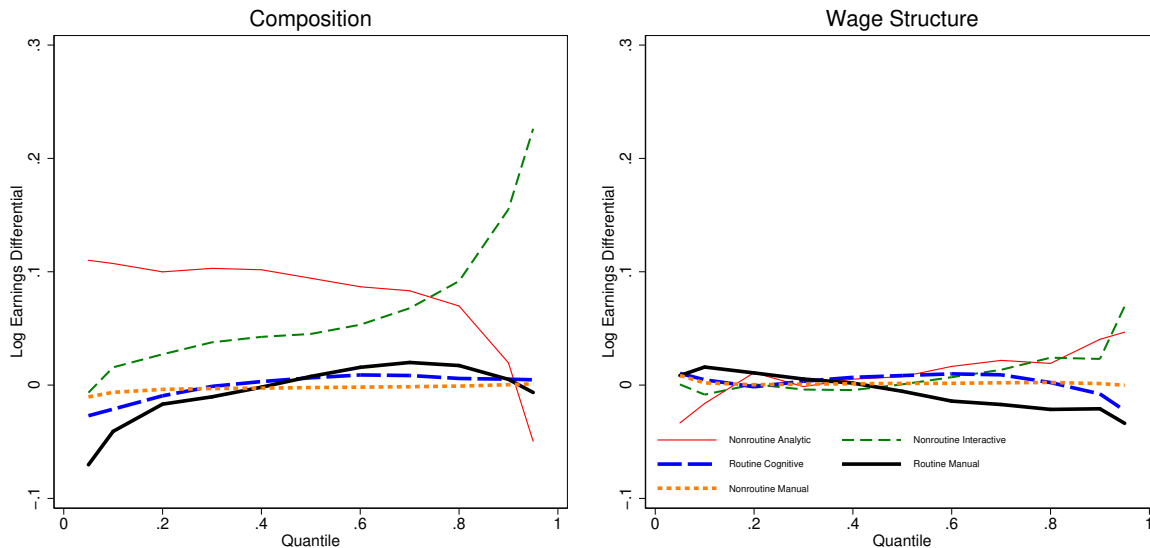
Finally, in [Figure 37](#), we plot the composition and wage structure effects. Unlike in [Section 5.1](#), the wage structure effects and composition effects account for a similar increase in labor earnings inequality.

Figure 34: Decomposition of Real Log Earnings: Wage Structure Effects, Boston and New York MSA Data



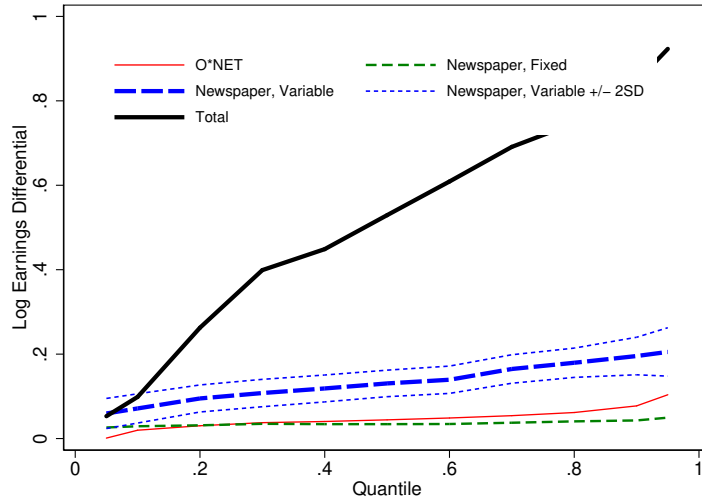
Notes: This figure describes the contribution of occupational characteristics through wage structure effects. The individual components of the wage structure effects can be found in Figure 35.

Figure 35: Detailed Decompositions: Boston and New York MSA Data



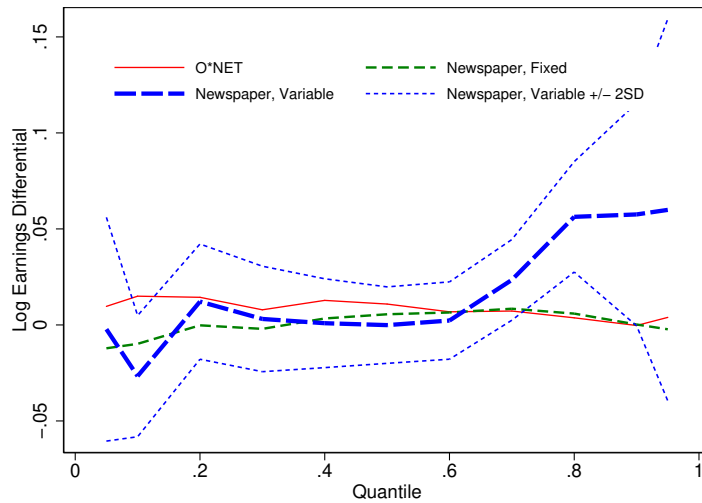
Notes: The panels describe the contribution of individual occupational characteristics, through compositional changes (left panel) and wage structure effects (right panel), to changes in the wage distribution. In this figure, we use the newspaper-based task measures that are allowed to vary within occupations across time.

Figure 36: Decomposition of Real Log Earnings: Composition Effects, Boston and New York MSA Data



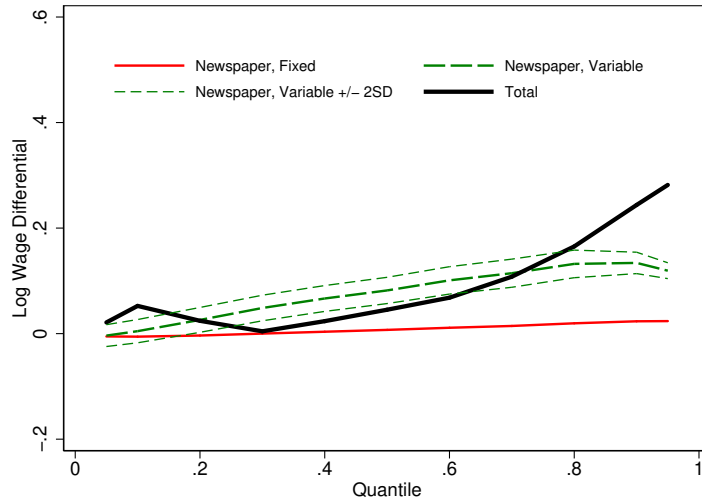
Notes: The thick solid line presents changes in log wage income of workers at different quantiles of the income distribution. The thin solid line and dashed lines give the contribution of occupations (through composition) using three different measures of occupational characteristics.

Figure 37: Decomposition of Real Log Earnings: Wage Structure Effects, Boston and New York MSA Data



Notes: This figure describes the contribution of occupational characteristics through wage structure effects.

Figure 38: Decomposition of Real Log Hourly Wage: MORG Data



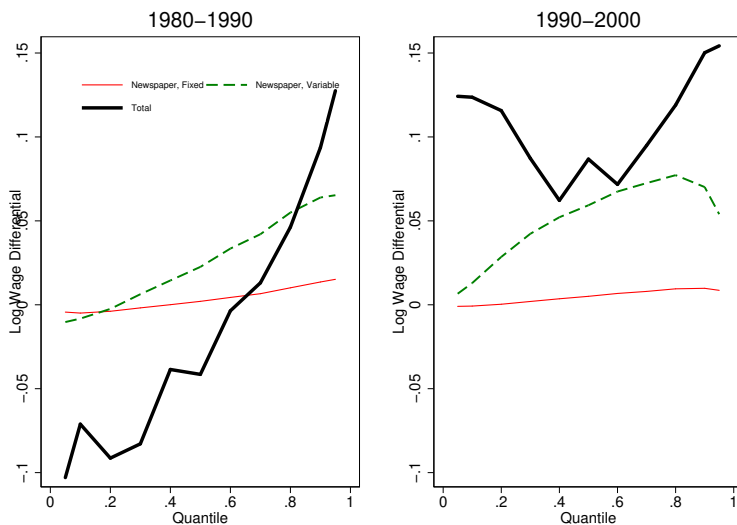
Notes: The figure describes the contribution of occupational characteristics through compositional changes, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks.

E.4 Decompositions That Use the CPS Merged Outgoing Rotation Group

[Firpo, Fortin, and Lemieux \(2014\)](#) used the CPS Merged Outgoing Rotation Group (MORG) to form the sample for their RIF-based decompositions (these authors used the 1976-1978 May CPS in the first few years of the sample, to extend the period over which union status could be measured.) In our baseline analysis, we used the decennial census, leading us to use workers' labor income earnings as an outcome measure (as opposed to hourly wages). We chose the decennial census to extend the sample period as far back as our newspaper data would allow, while recognizing that total labor income earnings are not the ideal measure of the demand for individual workers' labor. In this appendix, we recompute Figures 5 to 7 using data from the 1980-2000 MORG. As in the body of the paper, but unlike in Appendix E.3, our sample of workers includes those from the entire U.S. Over this period, the 90-10 and 90-50 ratios of hourly wages increased by 19 log points and 20 log points respectively.

Figures 38, 39, and 40 present decomposition results, now using [Spitz-Oener \(2006\)](#)'s task measures. In Figure 38, we plot the changes, via composition effects, accounted by our task measures. Our task measures account for a 13 log point increase in 90-10 wage inequality (with a two standard error confidence interval of 11 to 15 log points). This 13 log point contribution is somewhat larger than the total increase in earnings inequality, between 1980 and 2000, explained by our task measures when using our benchmark decennial census sample. (Unplotted, the wage structure effects account for a 4 log point reduction in 90-10 inequality.) In Figure 39, we plot the composition effects separately across the two decades. Here, the task measures account for a 7 log point increase in the 1980s and a 6 log point increase in the 1990s.

Figure 39: Decomposition of Real Log Hourly Wage: MORG Data



Notes: The figure describes the contribution of occupational characteristics through compositional changes, using [Spitz-Oener \(2006\)](#)'s definitions of routine and nonroutine tasks.

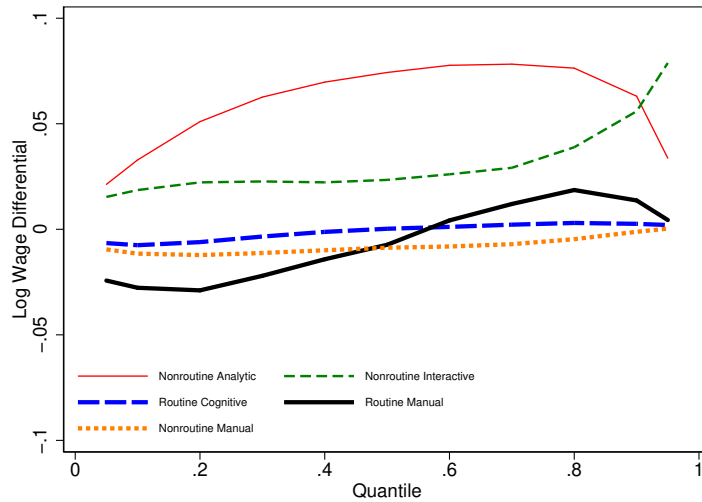
In [Figure 40](#), we plot the results from the corresponding detailed decompositions. As in the benchmark specification, changes in the composition of workers' jobs (measured by their nonroutine interactive and routine manual tasks) are the primary contributors of increasing wage inequality.

In [Figures 41 and 42](#), we re-compute our wage decompositions, now using [Firpo, Fortin, and Lemieux \(2014\)](#)'s occupational measures. [Firpo, Fortin, and Lemieux \(2014\)](#)'s measures of technological changes and offshorability account for a 13 log point increase in the 90-10 ratio (with the two standard error confidence interval of 0.10 to 0.16). Decompositions based on time-invariant occupational measures account most a 1 log point increase in 90-10 or 90-50 inequality.

F Details of the [Section 5.2](#) Model

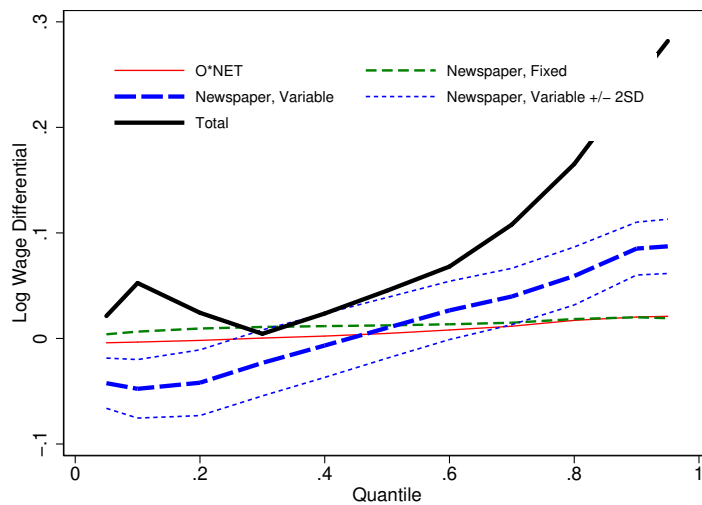
In this section, we describe the assumptions necessary to derive the empirical specification for our RIF regression decomposition from [Equation 4](#). We then delineate two algorithms: In the the first, we compute the counterfactual changes in groups' wages, and in the second we apply those changes in groups' wages to compute changes in the overall distribution (within-group and between group) of wages. Throughout this section use \hat{X} to refer to the ratio of variable X from one period to the next: $\hat{X} = \frac{X_{t+\tau}}{X_t}$.

Figure 40: Detailed Decompositions: MORG Data



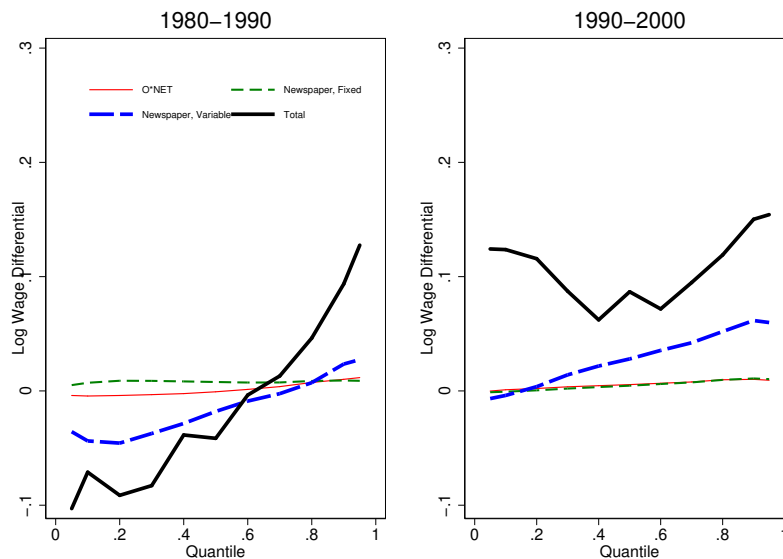
Notes: This figure describes the contribution of individual occupational characteristics through compositional changes, to changes in the wage distribution. In this figure, we use the newspaper-based task measures which are allowed to vary within occupations across time.

Figure 41: Decomposition of Real Log Hourly Wage: MORG Data



Notes: The thick solid line presents changes in log hourly wages of workers at different quantiles of the wage distribution. The thin solid line and dashed lines give the contribution of occupations through compositional changes, using three different measures of occupational characteristics.

Figure 42: Decomposition of Real Log Hourly Wage: MORG Data



Notes: The thick solid line presents changes in log hourly wages of workers at different quantiles of the wage distribution. The thin solid line and dashed lines give the contribution of occupations through compositional changes, using three different measures of occupational characteristics.

Linking the Model of Occupations as a Bundle of Tasks to the RIF Regressions

In motivating our RIF regression based decomposition, we begin by relating the price of occupation- j specific output with the prices of its constituent tasks:⁵³

$$\log P_{jt} = \log \pi_{0jt} + \sum_{h=1}^H T_{hjt} \log \pi_{hjt}. \quad (14)$$

In our model, perfect competition and homogeneous occupational output ensure that there is a single price for each occupation. Thus, although task prices π_{hjt} may vary by group reflecting the marginal value of each task in a production unit, these prices do not contribute to inequality once one takes into account the output price P_j . In other words, task prices only generate inequality between occupations. In contrast, the RIF regression specification, which allows for different task prices at different quantiles of the income distribution. One way to justify this, more flexible specification, is to assume that workers at different quantiles work in different occupations. Another is to consider a more flexible model where the unobserved shocks are not Hicks neutral in a given occupation, but rather task-specific.

Bearing in mind that additional flexibility, we can use the pricing Equation 14 in the

⁵³This is akin to the formulation in Yamaguchi (2012). To motivate this equation, suppose that workers cannot “unbundle” their tasks in the sense of Heckman and Scheinkman (1987). To the extent that tasks cannot be “unbundled,” task prices will differ across occupations.

wage Equation 4 to obtain an expression for wages as a function of tasks, task prices, and skills:

$$\log W_{ijt} = \log \pi_{0jt} + \sum_{h=1}^H T_{hjt} \log \pi_{hjt} + \sum_{h=1}^H T_{hjt} \log S_{gh} + \log \epsilon_{ijt}. \quad (15)$$

We next assume that individual i 's ability to perform task h at time t is linearly related to a set K of observable characteristics so that the underlying skill of group g individuals in performing task h can be written as $\log S_{gh} = \sum_{k=1}^K b_{hk} \tilde{S}_{gk}$. With this assumption, Equation 15 implies:

$$\log W_{ijt} = \log \pi_{0jt} + \sum_{h=1}^H T_{hjt} \log \pi_{hjt} + \sum_{k=1}^K \alpha_{kjt} \tilde{S}_{gk} + \log \epsilon_{ijt}, \quad (16)$$

where, again, \tilde{S}_{gk} is an observable skill characteristic k for an individual in group g .

Equation 2, in the body of the paper, would be equivalent to Equation 16 if one were to remove “j” subscripts on the π and α terms. But, insofar as workers in different occupations are concentrated at different points in the wage distribution, our coefficient estimates from Equation 2 will vary at different quantiles.

Algorithm to Compute Counterfactual Changes in Wages

1. Start with an occupational price guess $\hat{P}^{[0]}$.
2. Compute

$$\begin{aligned} \hat{W}_{gj}^{[1]} &= \hat{P}_j^{[0]} \prod_{h=1}^H (S_{hi})^{T_{hj}(\hat{T}_{hj}-1)}. \\ \hat{\lambda}_{gj}^{[1]} &= \frac{(\hat{W}_{gj}^{[1]})^\theta}{\sum_{j'} \lambda_{gj'} (\hat{W}_{gj'}^{[1]})^\theta}. \\ \widehat{W}_g^{[1]} &= \left(\sum_j (\hat{W}_{gj}^{[1]})^\theta \lambda_{gj} \right)^{1/\theta}. \end{aligned}$$

3. Compute the excess demand function

$$\begin{aligned} Z_j^{[1]} &= \hat{E}^{[1]} - \sum_{g=1}^G \widehat{W}_g^{[1]} \hat{\lambda}_{gj}^{[1]} \chi_{gj} \\ &= \sum_{g=1}^G \widehat{W}_g^{[1]} \Xi_g - \sum_{g=1}^G \widehat{W}_g^{[1]} \hat{\lambda}_{gj}^{[1]} \chi_{gj}, \end{aligned}$$

where Ξ_g and χ_{gj} are, respectively, the initial-equilibrium share of income earned by group g individuals and the share of group g occupation j in total labor payments.

4. Compute the new prices

$$\hat{P}_j^{[1]} = \hat{P}_j^{[0]} + \nu Z_j^{[1]}$$

for some small adjustment number ν . We also need to normalize $P_1^{[1]} = 1$.

5. Check for convergence. If there is no convergence, go back to 2.

Algorithm to Simulate the Distribution of Wages

Given $\bar{W}_{g,1960}$ and \widehat{W}_g (constructed from the previous algorithm), we now know $\bar{W}_{g,t}$. Note that the distribution of wages for each type g in this model is Frechet, with parameters $(\bar{W}_{g,t}, \theta)$. To get at the distribution of wages within the model:

1. Fix a large number \bar{L}^{sim} that controls the size of the simulation. We use $\bar{L}^{sim} = 10^6$.
2. For each group g , sample $\bar{L}^{sim} \times \sum_{j=1}^J \lambda_{gj}$ wages. To do so, draw for each observation in group i a unit exponential \mathcal{U} and then apply the transformation $W = \bar{W}_{g,t} \cdot \mathcal{U}^{-1/\theta}$.
3. The vector of all W is a sample of wages in this economy.

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