NBER WORKING PAPER SERIES

GENDER BASED OCCUPATIONAL SEGREGATION AND SEX DIFFERENCES IN SENSORY, MOTOR AND SPATIAL APTITUDES

Michael Baker
Kirsten Cornelson

Working Paper 22248
http://www.nber.org/papers/w22248

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
May 2016

We gratefully acknowledge the research support of SSHRC (#410-2011-0724) and a Canada Research Chair at the University of Toronto. Fran Blau kindly provided the occupational crosswalk for the 2000 Census occupational coding. We thank Dwayne Benjamin for helpful discussions, and Diane Halpern and Gary Solon for their input on an early draft. We also thank seminar participants at UBC- Kelowna and UBC- Vancouver. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Gender Based Occupational Segregation and Sex Differences in Sensory, Motor and Spatial Aptitudes
Michael Baker and Kirsten Cornelson
NBER Working Paper No. 22248
May 2016, Revised January 2017
JEL No. J16,J24,J62,J71

ABSTRACT

Research on sex differences in humans documents gender differences in sensory, motor and spatial aptitudes. These aptitudes, as captured by Dictionary of Occupational Titles (DOT) codes, predict the occupational choices of men and women in the directions indicated by this research. We simulate that eliminating selection on these skills reduces the Duncan index of gender based occupational segregation by 20-23 percent in 1970 and 2012. Eliminating selection on DOT variables capturing other accounts of this segregation has a smaller impact. In recent years, occupational selection on sensory, motor and spatial aptitudes works, on average, to lower the gender earnings gap.

Michael Baker
Department of Economics
University of Toronto
150 St. George Street
Toronto, ON M5S 3G7
CANADA
and NBER
baker@chass.utoronto.ca

Kirsten Cornelson
Department of Economics
University of Toronto
150 St. George Street
Toronto, ON M5S 3G7
CANADA
kirsten.cornelson@utoronto.ca

I Introduction

The male/female gap in labor market compensation has declined significantly over the past three decades in many developed countries. In the U.S., the female/male ratio of median annual earnings for full time workers has increased from 0.62 in 1979 to 0.83 in 2014 (BLS 2015). In countries that measure the gender gap in hourly earnings the female/male ratio is even higher—for example, in 2014 it was 0.88 in Canada (CANSIM) and in 2015 it was 0.91 in the UK (Office for National Statistics 2015). In comparison, the pace of change in the gender segregation of employment in recent decades has been glacial. In an early study of gender occupational segregation, Gross (1968) reported that the Duncan index[1] of segregation was steady at roughly 0.67 from 1900-1960. In the five decades since then, it has fallen by just 25%, to just over 0.50 in 2012. Most of this convergence was in the 1970's and 1980's; Blau et al. (2013) report that while the Duncan index declined by over 10 percentage points in the 1970s and 1980s, it declined by just over 3 percentage points in the following two decades. The index tells us that the overall segregation of males and females remains substantial: in recent years over half of men (or women) would need to change occupations for the occupational distributions of male and female employment to be the same.

It is important to understand why gender occupational segregation persists, as it accounts for part of the remaining gap between male and female compensation. While the within-occupation wage gap fell by nearly 50% from 1970 to 2012, the between-occupation component of the wage gap (the part related to gender occupational segregation) actually rose slightly over this time period. As a result, the proportion of the wage gap that is attributable to occupational segregation has increased, from around 20% in 1970 to 32% in 2012. Persistent segregation of

[1] The Duncan index, which is defined below, ranges between 0 and 1 and is interpreted to indicate the proportion of women or men who would need to change occupations to produce a similar occupational distribution of men and women.

the genders across occupations also implies that the sectoral change that accompanies economic growth is likely to have important effects on the relative compensation of men and women. For example, Borghans et al. (2014) argue that technological changes has increased the importance of interpersonal skills, thereby reducing the gender wage gap over time. Finally, if occupational segregation is of intrinsic policy interest, an effective response must be rooted in an understanding of its sources.

A large literature that attempts to explain occupational segregation has focused on three classes of explanations: gender differences in skills and human capital, gender difference in preferences for job characteristics, and gender based discrimination.[2] In this paper, we extend the literature relating gender differences in skills to occupational choice by examining the importance of sex differences in a set of labor market aptitudes and skills that, to our knowledge, have not been systematically highlighted in research on gender based occupational segregation. Our focus is on gender differences in sensory, motor and spatial aptitudes—for example, the sense of touch, fingering abilities and depth perception. There is extensive research documenting differences between males and females in these skills, many starting at very young ages. While these skill differences have received less attention than gender differences in other traits, they are nevertheless clearly relevant to job skills in many occupations.

We map the evidence of sex differences in these aptitudes into occupational aptitudes, physical requirements, working conditions and temperaments as captured by the Dictionary of Occupational Titles (DOT). We next relate these codes to different patterns of occupational selection by men and women. Specifically, we regress the log odds of male to female employment in an occupation on our DOT aptitude measures. In these regressions, we control for a number of other occupational characteristics that have been suggested as explanations for

[2] We review this literature in the next section.

gender occupational segregation, including measures of math and verbal demands, physical strength, people/things orientation, "occupational risk" (risk of death, competition and prestige), and time flexibility. With few exceptions, females and males select into occupations on the DOT occupational attributes in line with the predictions of the research on gender differences in motor, sensory and spatial skills, suggesting that the "lab" evidence has some implications for economic life.

A second contribution of our paper is that we quantify the potential contribution of motor, sensory and spatial skills to gender based occupational segregation by using a simulation model to examine how the Duncan index would change if we eliminated selection on these job attributes. We use the same procedure to assess the quantitative importance of our control variables, which attempt to capture alternative explanations for occupational segregation. This allows us to compare the relative importance of different hypotheses in explaining gender segregation within a common framework.[3]

We find that the aptitude that makes the largest sole contribution to gender segregation is the spatial content of employment. Eliminating differential gender selection on spatial skills alone would cause the Duncan index of segregation to fall by around 10% in both 1970 and in 2012. To provide perspective, eliminating occupational selection on physical strength reduces the Duncan index by 3.4% in 1970 and 6.3% in 2012. Eliminating selection on sensory, motor and spatial skills would reduce occupational segregation by roughly 20% in 1970 and 23% in 2012. This is larger than the combined effect of the control variables, which represent the more traditional explanations of gender segregation that have been explored in the literature.

Finally, we examine the implications of selection on motor, sensory and spatial skill

[3] Of course, this comparison is valid only to the extent that we succeed in representing these hypotheses using the DOT and O*NET variables.

measures, as well as on the control variables, for the gender wage gap. Holding wages and overall employment in an occupation fixed, we examine the effect on male and female average wages of eliminating differential gender selection on observable occupational attributes. This exercise highlights a somewhat surprising feature of skill-based occupational segregation: in many cases, it favors women in terms of compensation. Eliminating selection on physical strength or people/things orientation substantially increases the gender wage gap in both years, while eliminating selection on sensory or motor skills increases the wage gap in 2012 (but decreases it in 1970). This suggests that women's skill/preference profile on these measures is relatively beneficial. In contrast, eliminating selection on cognitive skills (particularly math), spatial skills and measures of occupational risk lead to a lower gender wage gap in both years, but particularly in 2012. These results also underline that the significance of the segregation of males and females in employment for the gender gap in pay is dependent on the relative prices of these skills at a particular time and place.

Our results suggest that a significant part of occupational segregation is related to gender differences in sensory, motor and spatial skills. To the extent that these differences are either biological (an issue on which we take no position) or difficult to manipulate through policy, this finding may help explain why gender occupational segregation has stopped declining in recent years. The piece of the wage gap related to occupational segregation may be easier to target, however, because it can be reduced by an economically significant amount through relatively small changes in the occupational distribution of men and women.

In the next section, we briefly review the existing literature on the sources of gender occupational segregation. In section III, we review the research on gender differences in sensory, motor and spatial skills. In our review, we summarize the current understanding of the possible sources of any sex differences and, where possible, document the ages at which the difference emerges. While our conclusions about the potential importance of skills accounting for labor market segregation do not depend on knowing anything about the origin of skill differences, this knowledge is important for formulating effective policies to address segregation. In section IV, we describe our data and empirical framework. Section V presents our regression results relating occupational attributes to the log odds of male employment, while sections VI and VII present simulation results quantifying the implications of differential skill selection on occupational segregation and the gender wage gap, respectively. Section VIII concludes.

II Previous Literature on Occupational Segregation

A large literature has documented the existence of occupational segregation, and examined its trends over time (e.g., Blau Weiskoff 1972, Blau et al 2013 and the overview in Blau and Kahn 2000). It has generated related investigations into the relative pay of male and female jobs (e.g., MacPherson and Hirsch 1995) and into the sources of segregation.

Attempts to explain occupational segregation have focused on three classes of explanations. The first examines the role of differences in human capital or skills. One emphasis here is on the role of social skills. Bacolod and Blum (2010), Black and Spitz-Oener (2010) and Borghans et al. (2014) all argue that women's advantage in people skills (see Gilligan, 2001 and Borghans et al. 2004), combined with an increasing return to social tasks, have contributed to the decline in the gender earnings gap over the past several decades. Another focus has been evidence that men outnumber women in the right-tail of the distribution on standardized math tests (Hedges and Nowell, 1995; Xie and Shauman, 2003; Ellison and Swanson, 2010). Because there is a link between math training and later career outcomes (see Weinberger, 2001 for a review), the gap in high-level performance has been hypothesized to be an important contributor to occupational segregation (particularly in STEM fields) and the gender earnings gap (see, for example, Spelke 2005 for a different interpretation of this evidence).

A second class of explanations argues that occupational segregation is related to gender differences in preferences for job attributes. A major emphasis of this literature is on women's hypothesized preference for jobs that provide flexibility to accommodate family responsibilities. An early paper in this vein is Polachek (1981), who argued that women have an incentive to choose jobs in which they are penalized less for extended family leaves. More recently, Goldin (2014) has highlighted the linearity of the wage schedule with respect to hours worked as a measure of family-friendly professions. Another set of preference-based explanations emphasizes gender differences in preferences for risk, competition and prestige. There is evidence showing that men seem to be less risk-averse (see reviews in Croson and Gneezy 2009 and Eckel and Grossman 2008), and are more responsive to competitive environments (Gneezy et al., 2003; Niederle and Vesterlund, 2007; see Cotton, McIntyre and Price, 2013 for a rebuttal of this evidence.) In line with this evidence, a number of papers show that men are differentially likely to select into jobs that have higher earnings or mortality risk (Deleire and Levy, 2004; Leeth and Ruser, 2006; Bonin, 2007; Grazier and Sloane, 2008.) Buser et al. (2014) show that men select into more prestigious academic tracks, conditional on ability. Several papers argue that a male preference for prestige and social comfort leads them to abandon occupations rapidly once they "tip" to being predominantly female (Akerlof and Kranton 2000, Golden 2013, Pan 2015). Another preference-based argument relies on men and women's different interests in working with things versus people (Su et al., 2009.) Pinker (2008) argues that this preference helps to explain differential selection into jobs. Finally other signals of gender differences in job/career preferences include that women are less likely than men to receive college degrees in

STEM fields even conditional on math test scores (Weinberger 1999) and females' job satisfaction declines in the proportion of men in their occupation, conditional on other occupational attributes (Lordan and Pischke 2016).

A third class of explanations of occupational segregation explores the role of discrimination. Several papers using matched pairs of applicants or randomized resumes have found discrimination against female applicants in male-dominated jobs and against male applicants in female-dominated jobs (e.g., Riach and Reich, 2006; Riach and Reich, 2002 for a review of other papers with similar results.) Goldin and Rouse (2000) show that when symphony orchestras adopt "blind" auditions (in which the candidates performed from behind a screen), women are significantly more likely to be selected.

Our contribution relative to this literature is twofold. First, we extend the research looking at the role of skills in occupational segregation to include a much broader set than have previously been considered. Gender differences have been established for a wide variety of sensory, motor and spatial skills that are potentially relevant for job performance, but the impact of these differences has not yet been comprehensively explored.4 Secondly, we simultaneously examine the impact of several of the explanations suggested in the literature (including math and verbal skills, interpersonal skills, time flexibility, risk, and people/things orientation) along with our new skill measures. To the extent that we successfully capture the competing explanations with our choice of variables from the DOT and O*NET databases, this tells us something about

[4] There is also a strand of research in sociology that has investigated the relationship between occupational gender segregation and occupational skills. For example, Bielby and Baron (1986) investigate the relationship between occupational segregation in a sample of firms in California in the 1960s and 70s and DOT skill measures. The basis for the hypothesized skill differences across genders is a contemporaneous summary of research on sex differences, primarily from psychology (Maccoby and Jacklin 1974). They conclude that neither the skills examined nor measures of turnover costs can account for the observed segregation. More recently Levanon and Grusky (2012) examine gender occupational segregation and a more comprehensive array of skill measures taken from the Occupational Information Network (O*NET) database. They conclude that physical and interactional social skills are particularly important. This research is complementary to economic research emphasizing males' physical/strength abilities and females' people skills.

the relative importance of different types of explanations.

Of course, the distinction between "skills", "preferences" and "discrimination" is somewhat artificial. If discrimination or social norms affect skill and preference formation, our results will also pick up the effect of these processes. While we consider this less likely for some of the sensory, motor and spatial skills that have stronger biological origins (for example, feeling or color discrimination), or are evident at very young ages, we do not rule out the possibility that discrimination contributes our results. Our analysis speaks to the potential role of realized skill differences between men and women in explaining occupational segregation; it does not tell us anything about the sources of these skill differences. It does, however, provide direction for future research in this area by identifying the skills that have the largest effect quantitatively.

III Gender Differences in the Skills and Abilities

Investigation of gender differences in skills and abilities is very active in many fields. This research has spawned popular debate through books that both support and condemn a biological interpretation of the differences between males and females (e.g., Brizendine 2007, Fine 2010; McCarthy and Ball 2011).

Explanations of gender differences fall into three general classes. The leading biological explanation, which is currently the focus of research in many fields, is prenatal exposure to hormones, and in particular androgens (see, for example Halpern 2012). Males have greater prenatal exposure to androgens, most significantly testosterone, and have higher levels of circulating testosterone post birth. The higher prenatal and postnatal exposure to androgens is hypothesized to have organizational impacts on the developing brain. For example, it is thought to accentuate functions that are controlled by parts of the brain that have relatively high numbers of androgen receptors.

Evidence in favor of these theories is constructed by relating levels of prenatal androgens to specific skills. There are also investigations of the relative abilities of children who are exposed to greater levels of prenatal androgens than the norm—for example different sex dizygotic twins and children with congenital adrenal hyperplasia (CAH)—and variation in abilities according to natural or synthetic variation in hormones (e.g., menstrual cycles and hormone replacement therapy).

A second class of explanations is founded on evolutionary principles of natural selection and the traditional gender roles in hunter/gatherer societies. The hypothesis is that natural selection has favoured the reproduction of males with "hunting skills" and females with "gathering skills". The support for this explanation is through interpretation of gender differences through this lens. For example, a male advantage in targeting distant objects reflects a hunter past, while a female advantage in fine motor skills echoes a foraging background.

The third class of explanations is that any gender differences are environmentally determined. Girls and boys are viewed as equally endowed, but they are subsequently subjected to different circumstances as a result of cultural norms and/or differential access to power. For example, males' affinity for things and females' affinity for people might be traced through a lifetime of dichotomous stimuli, perhaps starting with the truck/doll divide in childhood. Unfortunately, simple documentation of gender differences in these environments does not provide much leverage to test this explanation. For example, Dickens and Flynn (2001) argue genes and environment are matched in ways to amplify what might initially be a modest genetic based difference. Absent controlled experiments, the primary leverage to test the environmental explanation is to discover whether gender differences in traits are present at very young ages before the effects of social environments can have much effect.

While not strictly speaking an explanation, it is also important to note that another participant in this debate is an argument that the evidence does not support any gender differences in traits. The "gender similarities hypothesis", associated with Hyde (2005), maintains that based on meta analyses most effect sizes—the standardized difference in means—of male/female differences are either close to zero or small (in general less than 0.35).[5]

At present there is no clear winner among these opposing views. Currently biological explanations attract much of the research and much of the controversy. Our analysis does not shine any new light on the origins of sex differences in skills and aptitudes. For our purposes the more important consideration is whether any differences are present before occupational choices are made so they are not the result of learned occupational experience. The debate about the origins of sex differences is relevant, of course, to the formulation of policies designed to address any differential selection into occupations on the basis of skills.

Finally, much of the criticism of the use of research on sex differences to explain everyday life is rooted in speculation of what the differences might mean versus speculation that effect sizes of certain magnitudes must not mean anything. We instead ask the empirical question of how occupational selection lines up with the researched sex differences, conditional on our mapping of the sex differences into DOT codes.

Gender Differences in Sensory Functions

Gender differences in some sensory functions have long been reported (Velle 1987). Certain differences have an explicit genetic origin, such as colour blindness. For others the exact source is still under investigation, although they are well documented (see also Halpern 2012, 105-107 for an overview).

[5] Our focus is on sensory, motor and visiospatial gender differences that are mostly not covered in Hyde's evidence and/or are more generally regarded as areas in which gender differences do exist.

Vision—One dimension of gender differences in vision has a clear genetic source. The incidence of colour blindness is much higher in males than in females because the most prevalent forms (red/green) are a result of gene deletion or damage on the X chromosome. Because females have two X chromosomes and males have one, and color blindness is a recessive trait, this result of genetic abnormalities of this chromosome is more likely to be inherited by males.

While there is a large gender difference in the incidence of color blindness, the overall incidence is small enough that color blind individuals may be easily able to match with jobs that do not require color discrimination skills. Recent research, however, suggests that, within a sample of college students, females exhibit greater sensitivity to colour than males in populations with normal vision (Handa and McGivern 2015; Abramov et al. 2012b, Murray et al. 2012), while in a sample of 16-23 month old infants a higher proportion of females could distinguish colours (Mercer et al. 2014).

Research into gender differences in vision other than color blindness is relatively recent, and a proposed explanation is males' higher levels of androgen exposure. For example, adult males exhibit better visual acuity—sensitivity to fine detail and rapidly moving stimuli (Velle 1987, Abramov et al. 2012a). A suspected cause is the high number of testosterone receptors in the cerebral cortex. Environmental factors may also play a role, as there is evidence that vision acuity can be improved through training (Ward et al. 2008; also see Halpern, 2012). Finally, evolutionary explanations have also been forwarded based on the distinct gender roles in hunter/gatherer societies (Abramov et al. 2012a).

This same evolutionary hypothesis has led researchers to look for sex differences in the visual perception of near and far space. Recent research has provided evidence of the better accuracy of females in near space and of males in far space in a sample of young adults (Stancy and Turner 2010), and similar gender differences in puzzle solving (Sanders et al. 2007b).

Hearing—Females have been observed to have a higher degree of auditory sensitivity than males (detecting weak sounds in quiet), especially at higher frequencies, starting in childhood (Halpern 2012, McFadden 1998, Velle 1987). Conversely, males have been observed to have a higher tolerance of noise, again starting in childhood (Velle 1987). Roughly speaking females have been found to experience a given noise level twice as strongly as males. Males are observed to have better abilities in sound localization, have a larger right ear advantage and better at distinguish signal sounds through masking sounds (McFadden 1998).

Among older populations environmental factors are thought to contribute to sex differences in hearing. However, these are less likely factors for differences found among children. One branch of current research is on the impact of androgens on the development of auditory function. For example, the higher exposure of males to androgens in the prenatal period is thought to weaken cochlear amplifiers. Males have weaker otoacoustic emissions than females, even at very young ages (McFadden 2002, McFadden 2008, Halpern 2012).

Taste and Smell—Females have been observed to have a better sense of smell and taste. The documentation of sex differences in the sense of smell has a long history and is widely believed (see Brand and Millot 2001 for a survey). While sex differences have not been observed for the sensitivity to, or ability to, discriminate all smells, where they are detected they always indicate greater ability for females—Halpern (2012, p.106) reports that the advantage "extends across the entire lifespan". Environmental explanations have been offered for these differences—females may have a larger learned experience with odours. However, evidence of sex differences at early ages and female superiority at identifying "male" odours suggests there are other factors at play. Candidates for explaining this difference are sex differences in anatomy, brain structure and/or function, evolutionary functions and gender differences in verbal ability. The evidence on sex differences in taste recognition and perception are more mixed suggesting females perceive some tastes better, but others not as well (Halpern 2012 107).

Touch—Finally, females have been observed to have a better sense of touch, a finding for both blind and sighted subjects and so distinct from sex differences in visual acuity (Halpern 2012). At least one dimension of this difference appears to be biological. Perception of textures is related to the density of sense perceptors—Merkel cells—in the hand. Smaller hands have a higher density of these cells. Therefore female's smaller stature and smaller finger size, on average, leads to their better perception of textures (Peters et al. 2009). Touch sensitivity has been found to be similar between men and women with similar finger size.

Gender Differences in Perceptual Motor Tasks

Motor Abilities—There is evidence of sex differences in some motor and visual coordination tasks. Tests of abilities for aiming at moving or stationary targets appear to favour males by a relatively large margin (Hall and Kimura 1995, Watson and Kimura 1991, but also see Auyeung et al 2011), while females demonstrate an advantage in fine motor dexterity (Nicholson and Kimura 1996). Tests of both these abilities find similar sex differences among young children (Sanders and Kadam 2001).

Common tests of these abilities have been criticised for conflating any sex differences in perceptions of near and far space with any sex differences in specific motor skills. Controlling for sex differences in space, Sanders et al. (2007a) present evidence that females perform better in finger tasks while males perform better in arm tasks.

Recent research takes up this distinction between a gross motor movement advantage for males and a fine motor movement advantage for females (see Sanders 2013 for an overview).

For example, females have an advantage in movements of the wrist and fingers (Sanders and Walsh 2007, Sanders and Perez 2007). Finally, a male advantage has also been observed for tests of reaction time and finger tapping (Roivainen 2011).

The origins of these differences have not been isolated but evolutionary and (because this skill can improve with practice) environmental sources are possibilities. Prenatal testosterone exposure may also play a role as the 2D:4D digit ratio appears to predict targeting performance (Falter et al. 2006). Sanders (2013) cites recent evidence that hand and arm muscle manipulation are controlled by the brain's primary motor cortex via different "tracts" and there is recent evidence of sex differences in the regions of the brain associated with motor control.

Perceptual Motor Tasks—Sex differences in some perceptual motor tasks, especially those involving digits and alphabets, appear to favour females (e.g., Roivainen 2011). These include perceptual speed, fine motor manipulations and tactile skills. For example, females have an advantage in the "Digit Symbol" task (formerly part of the Wechsler Scales) but not the "Inspection Time" task (Halpern 2012, Burns and Nettelbeck 2005). A female advantage in the Processing Speed Index of the Wechsler scales has been reliably found in a sample of primary and secondary school aged children (Longman et al. 2007).

Some of these differences are again attributed to females' smaller stature, on average—females' smaller hand size on average might contribute to their advantage in fine motor tasks (Peters et al. 1990 and Peters and Compagnaro 1996).

Gender Differences in Visiospatial Abilities

Sex differences in visiospatial abilities have been widely documented and in general favour males. The advantage is not uniform, however. Halpern (2012) in her review reports a male advantage in spatial perception, mental rotation, spatiotemporal ability, and to a lesser extent, spatial visualization. The evidence for abilities related to the generation and maintenance of a spatial image are mixed. Females have an advantage in remembering the spatial location of objects in an array (Sanders 2013). [6] There is evidence that the gender difference in some of these abilities emerges at very young ages (e.g., Moore and Johnson 2008, Quinn and Liben 2008). Among high school seniors, Baker and Cornelson (2016) report a gender gap in a test of three dimensional mental rotation favouring males of 0.388 of standard deviation in 1960 and 0.253 of a standard deviation in 1980.[7]

Recent research emphasizes that in summarising this literature it is important to consider variation in the difficulty of the skill test across studies and the possible conflation of different skills within a single test. For example, Sanders (2013) argues that the evidence indicates a strong male advantage in coincidence-anticipation timing (CAT—for example, the ability to predict when a projectile weapon will reach a moving target), in children and adults, predominately in easier rather than harder CAT tasks. CAT skills are useful for activities such as sports and driving. Also, as noted above common tests of targeting and motor abilities potentially conflate sex differences in motor functions and sex differences in perceptions of near and far space. Sanders (2013) reports that there is good evidence of a male advantage in the processing of far space and a female advantage in the processing of near space, although there are also some anomalous studies.

An androgen based explanation of male advantage in visual spatial skills has been forwarded based, for example, on the higher spatial performance of females with CAG (Miller and Halpern 2014). Sanders (2013) notes that near and far space are processed by different mechanisms in the brain, setting the stage for sex differences in the development of these

[6] Newcombe (2010) provides the evidence against this claimed female advantage.
[7] For 1960 they report a gender gap, controlling for age, of 0.275 standard deviations for high school freshman and 0.415 for high school seniors.

mechanisms to be important. However, there is also evidence that measures of the gender difference in spatial abilities vary across countries according to some measures of socio-economic development, although not always in expected ways (e.g., Lippa et al. 2008). In addition, there is evidence that mastery of spatial skills is responsive to training (e.g., Miller and Halpern 2013, Hyde 2014). Finally, because there is no explicit training in visual spatial skills in schools, the sex difference may reflect gender differences in extra-curricular activities such as participation in sports and computer use (e.g., Cherney and Voyer 2008).

IV Data and Empirical Framework

Occupational Characteristics Data

To link the sex differences documented in the last section to occupational segregation, we use information on occupational skill requirements taken from the 1977 and 1991 editions of the DOT. The DOT, first published in 1939, was originally intended to help match workers with appropriate jobs. It rates each of several thousand occupations along a number of dimensions such as aptitudes, temperaments, interests and physical demands. In Table AI of the appendix, we describe the DOT measures that we believe are most closely linked to the sensory, motor and spatial aptitudes that consistently show sex differences, as outlined in the previous section.

The DOT measures were not derived with the intent to measure the same skills and aptitudes in which researchers have documented sex differences. Our mapping, as summarized by our hypotheses of expected signs of any male/female sex difference, is necessarily rough.

A couple of comments are warranted before proceeding. First, the evidence for sex differences in the senses of taste and smell are at best mixed, and the explanations include corresponding sex differences in lived experience. This leads to the direct possibility that the sex segregation in occupations due to some other factor leads to the measured sex differences in the senses of taste and smell.

Second, in the area of motor skills, as noted above a way to organize the sex differences is in the categories of fine and gross motor skills. Many of the skills and aptitudes with a documented female advantage are considered fine motor skills and, as Halpern (2012) observes, many studies support such a generalization. The DOT categories of fingering, finger dexterity, handling and motor coordination—the ability to coordinate eyes and hands or fingers with speed and accuracy—are more clearly associated with this category. Eye-hand-foot coordination—the coordination of hands and feet with visual stimulae—we view to involve arm and leg coordination which are gross motor abilities. Clerical perception—the ability to perceive details in tabular or verbal input—has been long associated with the female advantage in perceptual motor skills, but also, controversially, has been used to argue females are better suited for clerical jobs. Finally, we are agnostic about the coding of manual dexterity, which involves working with both arms (a male advantage) and hands (a female advantage).[8]

To assess the relative importance of sensory, motor and spatial skills compared to other explanations of occupational gender segregation, we also attempt to capture an occupation's i) overall physical demands, ii) math and verbal skill requirements, iii) people/things orientation, iv) degree of risk and competitiveness and v) time flexibility. As outlined in our review of the occupational segregation literature, all of these factors may be related to men and women's occupational choices.

To capture an occupation's physical demands, we use the DOT variable "physical strength". Physical strength represents a relatively uncontroversial and well-understood gender

[8] We do not make use of the DOT physical demand codes kneeling, climbing, balancing, stooping, crouching, crawling, talking and reaching. We also exclude the aptitude form perception (the ability to perceive pertinent detail in pictures and graphs) and the physical demands accommodation (the adjustment of the eye to bring things into focus), and field of vision.

skill difference; as such, this variable provides a useful benchmark for evaluating the impact of other skills. For math and verbal demands, we use the DOT General Educational Development scales for math and language, respectively. Our measures of people/things orientation are the DOT variables "Temperament – dealing with people" and "Interests – working with things".[9]

To capture an occupation's degree of risk and competitiveness, we use three measures. For risk, we include an occupation's mortality rate, derived from the Bureau of Labor Statistic's Census of Fatal Occupational Injuries. We use information on the number of fatalities for each occupation in 2012, [10] and convert this to a mortality rate using employment information. To measure competition, we use a variable from the O*NET database. O*NET is a database produced by the U.S. Department of Labor that has supplanted the DOT in recent years. It provides many similar measures of occupational requirements as the DOT, but also has a number of additional characteristics. To capture the competitive pressure in an occupation, we use the O*NET work context variable "level of competition." Finally, to capture the fact that competitiveness may lead men to be more sensitive to prestige (as suggested by Buser et al. 2014), we also include the occupational prestige score proposed by Nakao and Treas (1994). This is based on data from the 1989 General Social Survey, in which respondents were asked to rank occupations on scale of social standing from 1 to 9. While the initial scores were based on the 1990 Census occupational coding, we obtain the measures for the 2000 Census occupational coding using data from IPUMS (Ruggles et al., 2010).

For measures of time flexibility, we use Goldin's (2014) proposed measures from the O*NET database. Goldin (2014) argues that non-linearity of the wage reward with respect to

[9] As shown in the robustness table in the Appendix, alternative measures of social demands produce similar results.
[10] The earliest fatalities data are from 1992. Because these data are provided for different occupational codes, however, we can only match them to 431 Census 2000 occupations (as opposed to the 468 used in our main analysis.) The results are similar if we use the 1992 fatalities information for our 1970 analysis.

time input helps determine the male-female wage gap. This non-linearity in turn is affected by an occupation's time demands, the degree to which it requires structured versus unstructured work, the freedom its employees have to make decisions, and the extent to which it requires contact with others and the maintenance of interpersonal relationships. Because we will be using other measures of an occupation's interpersonal demands, we use only the first three O*NET measures (the O*NET characteristics "time pressure", "structured vs. unstructured work" and "freedom to make decisions") as our measures of time flexibility. The coefficients on all three variables are expected to be positive.[11]

Occupations

To examine male-female occupational segregation and its relationship to occupational skill requirements, we link the DOT measures and the other occupational characteristics to occupations in the decennial Censuses from 1970-2000, and the 2012 3-year American Community Survey (denoted as 2012). We use the crosswalk developed by Blau et al. (2013) to convert occupations in the earlier Census years and the ACS to the 2000 Census occupational coding (see details in the Data appendix.)

The DOT uses an internal coding system, but the 1977 data are also linked to a CPS file that provides 1970 Census occupational codes. We use these to match both 1991 and 1977 DOT codes to 2000 Census occupations. In this way, we were able to link DOT ratings to 476 of the 505 Census occupational codes. (See the Data appendix for a further description of this process.) Because the DOT contains more detail than the Census occupation coding scheme (so that each Census code contains a number of DOT occupations), we average the ratings across all DOT occupations within a Census code, with weights corresponding to that occupation's share of

[11] Note that the "structure" variable is reverse-coded in the O*NET, with higher values indicating more freedom for the worker to determine tasks, priorities and goals.

employment. This means that, although most of our DOT measures are categorical, they are continuous within our data. When possible, we assign occupations their 1977 DOT measures for the 1970 and 1980 Censuses, and the 1991 DOT measures thereafter. This is not possible with the physical demands[12] and certain environmental conditions, however, which are only available in 1991; for these measures, we use the 1991 measures for all years.

Both the O*NET measures and the fatality information from the Census of Fatal Injuries are provided at the SOC occupation level. To convert these measures to Census 2000 occupational codes, we use a crosswalk provided by the U.S. Census Bureau. We were able to link O*NET measures to 468 Census occupations (all of which also have fatalities information), which provide the final sample of occupations for our analysis. These occupations account for 98.4% of the U.S. workforce in 2012, and have a Duncan index that is nearly identical to the Duncan index for the U.S. workforce as a whole.

Empirical Framework

Our objective is to estimate Duncan indices of gender occupational segregation net of any gender occupational selection on occupational differences in the DOT sensory, motor and spatial attributes. The Duncan index is defined as

$$D = (0.5) \cdot \sum_j |m_j - f_j|$$

where f_j is the fraction of all employed women who work in occupation j and m_j is the fraction of all employed men who work in occupation j. The index, which ranges between 0 and 1, is commonly interpreted to indicate the proportion of women or men who would need to change occupations if the occupational distribution of men and women were to be the same.

To proceed, we start by estimating the relationship between our occupational attribute

[12] Excepting physical strength, which is available in both years.

measures and the relative probability that men and women select into an occupation. Specifically, we regress the log odds of male to female employment in an occupation on our measures of occupational characteristics. The log odds are defined as:

(1) $$l_j = \ln\left(\frac{\frac{m_j}{(1-m_j)}}{\frac{f_j}{(1-f_j)}}\right)$$

The term $f_j/(1-f_j)$ represents the odds that a randomly selected, employed female works in occupation *j*. The ratio of these odds for men and women tells us about the relative likelihood that men and women select into occupation *j*.[13] Our main regression equation is:

(2) $$l_j = \alpha + \beta S_j + \varepsilon_j$$

where S_j are measures of the characteristics of occupation *j*.

We use the results of estimating (2) to simulate the effect of removing any differential selection on skills across occupations. To do this, we first predict the log odds for each occupation that would occur if a particular set of occupational characteristics did not differentially affect the occupation choices of men and women. Let S_k denote a subset of occupational characteristics, and S_{-k} denote all of the remaining occupational characteristics. The predicted log odds for occupation *j*, eliminating differential gender selection on the characteristic set *k* are:

(3) $$\hat{l}_j = \hat{\alpha} + \hat{\beta}_{-k}S_{-k} + \hat{\varepsilon}_j$$

Next, we find the unique occupational shares, $\hat{f}_j$ and $\hat{m}_j$, that solve these log odds and also keep each occupation's total share of employment at its actual level (this yields 936 equations in 936

[13] Alternatively, we can write the odds ratio as the male-to-female ratio in occupation *j* over the male-to-female ratio in all other occupations. If *j* is small relative to the labor market, this denominator of this equation is approximately equal to the male-to-female ratio of total employment. The odds ratio therefore tells us about how far the sex ratio in an occupation deviates from the norm for the labor market.

unknowns).[14] Finally, we construct Duncan indices from these predicted shares.

In order to evaluate whether these predicted indices are significantly different from the actual Duncan index in each year, we compare them to a distribution of Duncan indices constructed from 500 rounds of resampling from the actual data. They tell us the probability of observing the given level of the Duncan index in an economy that actually had the same underlying selection behaviour as the actual economy. Because the sample size is large, this procedure produces bounds that are quite narrow: the resampled Duncan indices vary from the actual Duncan index only at the fourth decimal point. As a result, all of our estimated Duncan indices are significantly different from the actual Duncan index at the 1 percent level. We therefore omit the standard indications of significance from the tables showing the simulated Duncan indices.

We also simulate the potential implications of gender selection on occupational characteristics for the gender earnings gap. We decompose the observed male/female difference in average earnings as a function of average earnings and the proportion of males and females employed, at the occupation level.

(4) $$w^m - w^f = \sum_j (m_j - f_j) \cdot w_j^m + \sum_j (w_j^m - w_j^f) \cdot f_j ,$$

where w_j^i is average earnings in occupation *j* for sex *i=m,f*, and f_j and m_j are defined as above. The first term on the right hand side of (4) is the part of the difference in average earnings that is due to differences in the employment of males and females across occupations, while the second term is the part due to male/female differences in earnings within occupations. We then simulate

[14] This procedure produces occupation shares m_j and f_j that do not add up to one, which is a problem for the interpretation of the Duncan index. We solve this problem by rescaling so that the shares do add up to one, i.e. by allowing the total number of men and women in the labor market to change. In practice, the changes in the total size of the labor force are fairly small – about 3% for men and 1% for women.

the all else equal male/female average earnings gap net of selection on sensory, motor and spatial skills by substituting $\hat{f}_j$ and $\hat{m}_j$ into (4).

V Regression Results

An Overview of Gender Occupational Segregation

We begin our analysis in the first row of table 1 with estimates of Duncan index of occupational gender segregation in the American labor market by census year and for 2012 based on ACS data. While the estimates differ slightly in magnitudes from those in Blau et al. (2013), they tell the same story. The change in the Duncan index between 1970 and 1990 is more than 10 percentage points, while in the next 22 years it is less than 4 percentage points. In 2012 just over half of men or women would need to change occupations for the occupational distribution of males and females to be the same.

In the next five next rows we list the five occupations that make the largest contributions to the Duncan index in each year. They are very stable over time—secretaries and administrative assistants make the largest contribution in every year. Registered nurses and bookkeeping clerks appear in four of the five years. In the seventh row we report the proportion of the Duncan index contributed by these top five occupations. It declines gradually from 13.3 to 8.8 percent over the period. This is an initial indication that quantitatively the Duncan index is relatively concentrated in few occupations, as there are 505 occupational categories in each year.[15]

A recent focus of economic research on occupational segregation is STEM occupations. While there are many reasons to focus on these occupations, their contribution to overall gender employment segregation is not one of them. In the next row we report for each year the

[15] In Table 1, we report results for all 505 Census occupation categories. Once we move to the analysis of skills, we will be restricted to the 468 occupations that can be matched to DOT codes. This makes very little difference: the Duncan index for our 468 occupations is 0.644 in 1970 (the same as when we use the full set of occupations) and 0.508 in 2012 (versus 0.506 for all occupations.)

proportion of the Duncan index represented by segregation in these occupations. It is quite steady averaging around 2.5 percent over the period.[16]

In the final rows of table 1, we report the total number of occupational categories with positive employment in each year, and indicators of the importance of the occupations making the largest contributions to the Duncan index to overall gender segregation. For example, just 25-30 occupations in each year, or just 6 percent of the total number, can account for 50 percent of the Duncan index. There are no STEM occupations in this group, and in 2012 they represented over 29 percent of male employment and 45 percent of female employment. In each year roughly 170 of 505 occupations can account for 90 percent of the Duncan. These results amplify the message of the top 5 occupations. Gender occupational segregation is a story that is concentrated in a relatively small number of occupations.

Gender occupational selection on aptitudes

In Table 2, we present the results of univariate regressions individually relating the variables capturing more traditional explanations of gender segregation to the log odds of male employment. The first row shows a coefficient from a regression of the log odds of male employment on the DOT variable for physical strength. All occupational attributes are normalized to have mean 0 and standard deviation one, so the estimates are interpreted as the change in the log odds associated with a one standard deviation increase in a skill. As expected, occupations with higher demands for physical strength have higher log odds, indicating that there are more men in these occupations. This effect is substantial:. a one standard deviation increase in the physical strength measure is associated with a 0.723 increase in the log odds of male employment in 1970 and a 0.996 increase in 2012. In 2012 the odds of male employment are just over 270 percent (exp(0.996)) higher than the odds of female employment in an occupation

[16] Our definition of STEM jobs is from the U.S. Department of Commerce (2011).

one standard deviation above the mean in physical strength. The DOT physical strength variable alone accounts for 14% of the variation in the log odds in 1970, and 32% in 2012

In the next row, we show corresponding results for the DOT variables "GED – language" and "GED – math", which are intended to capture men's purported disadvantage in verbal skills and advantage in math. The math variable significantly predicts a higher male share in 1970, but a lower male share in 2012, while the language variable predicts a higher female share in 2012. However, these variables account for a smaller proportion of the variation in the data with R^2s of 1.5%-8.0%. In the next two rows, we examine the effect of variables corresponding to the people/things dichotomy. These variables have a strong and significant relationship to the log odds, in the expected directions: occupations requiring a temperament for dealing with people have more females, while occupations requiring an interest in working with things have more men. The variables relating to mortality risk, competitiveness and prestige are all strongly related to the log odds in the expected direction, with the R^2 ranging from 2-11%. Finally, we examine the time flexibility measures proposed by Goldin (2014). As hypothesized,, occupations with high time pressures and more freedom to make decisions tend to have relatively more males in them (although the second relationship is significant only in 1970.) However, occupations that are relatively less structured have significantly *fewer* men in 2012. The R^2s for each these variables are relatively small, suggesting these variables potentially have a lower profile in an account of occupational segregation.[17]

In Table 3, we examine the corresponding univariate results for the sensory, motor and spatial aptitudes. In the first panel are the estimates for the sensory skills—color vision, visual

[17] Note however that a variable may have a high R^2 in predicting the log odds across occupations, but very little aggregate effect on the Duncan index if either the skill does not vary substantially across occupations, or if its variation is primarily concentrated in very small occupations (which are weighted equally with large occupations in the log odds regressions.)

acuity, auditory sensitivity, the sense of taste and smell and feeling. The results for color vision and color discrimination are not of the expected sign, while the estimates for the remaining skills are. Larger estimates are observed for far acuity and the two measures of auditory sensitivity. The noise attribute alone can account for 44% of the variation in the data in 2012, and the estimated association with the log odds ratio for this attribute in each year is larger than the estimate for physical strength.

Estimates for the motor skills are presented in the next panel. Here most of the estimates are of the expected sign, with the exception of motor coordination and handling in 2012. As noted above, the manual dexterity attribute involves both arms and hands and thus we do not have a definitive prediction of a sign for the effect. The result here indicates a positive association with male employment. The estimated association for this attribute, along with those for eye-hand-foot coordination and clerical perception, is relatively large, especially in 2012.

In the final panel are the results for spatial attributes. For both measures of spatial perception the estimates are right signed and very large –in fact, typically larger than the estimated coefficient on physical strength. The estimate for spatial skills falls by about 1/4 from 1970 to 2012; the coefficient on depth perception, however, increases slightly over this time period. By 2012, this single skill measure can account for 42% of the variation in log odds ratio.

The fact that some of the estimated coefficients are of the wrong sign in Tables 2 and 3 could be explained by the fact that occupational characteristics are not independent of one another. Men may work in jobs that are more reliant on color vision, for example, because these jobs also demand aptitudes for which they are relatively advantaged, or because these jobs have other characteristics that men tend to value more than women. To understand the relationship between occupational characteristics and the log odds, conditional on overall occupational characteristics, we next present results based on a full model in which all attributes are included simultaneously. The results of these regressions are shown in Table 4.

The statistically significant estimates from these regressions are now all of the expected sign, with one exception (eye-hand-foot coordination in 1970, although this is relatively unimportant quantitatively.) Among the sensory attributes, noise and feeling are the strongest and most significant predictors of the log odds. The motor skills, on the whole, do not appear to have a strong relationship with male and female selection into occupations. Both of the spatial measures are strongly and significantly related to the log odds of male employment in both years. Among the variables capturing competing hypotheses, the significant predictors of the log odds are physical strength, GED – math, interest in working with things, the level of competition and freedom to make decisions. Comparing the partial R^2s of these variables indicates that spatial aptitude is the strongest predictor of the log odds in 1970, followed closely by things orientation. Physical strength and GED – math are also strongly related to the log odds. In 2012, the strongest predictor is competition, following by feeling, noise and physical strength. The spatial variables also have a strong relationship to the log odds.

In the appendix we report how the results change in a series of robustness checks. These include adding the ratio of male to female wages and average weekly hours[18] at the occupational level as additional occupational attributes, omitting nominally duplicate skill measures (e.g., color vision and color discrimination) and investigating alternative DOT measures of people skills. Each of these modifications has little impact on the inference. We also estimate models that use either only the 1970 or 1991 DOT definitions for both the 1970 and 2012 data, which lead to minor changes in inference for one or two attributes. Finally, we have calculated the log

[18] Weekly hours are provided in intervals in the 1970 Census data; we use the midpoint of each interval to impute weekly hours.

odds ratio separately for the age groups 18-24, 25-34 and 35-64 and estimated the pooled regression testing for interaction effects between dummy variables for the younger age groups and the DOT aptitude measures. The estimates of these interactions for both age groups and in both years are uniformly statistically insignificant.

The message of this analysis is that estimated relationships between the male to female log odds ratio and the DOT measures of sensory, motor and spatial aptitudes are the majority of the sign predicted by the cited research on sex differences. In the more comprehensive specifications, a challenge to isolating the relationships for individual skills is the multicollinearity among them.[19] Furthermore, the estimates for the attributes/skills of noise, feeling, spatial and depth perception stand out as making an empirically unique contribution to the log odds employment ratio, on a similar scale to the contributions of physical strength, GED—math, interest in things and competition. We note that the analogues of these DOT skills in the research literature—hearing, hand and finger sense and spatial perception—are among the least controversial and widely acknowledged sex differences, and ones that have been documented at young ages.

VI The Association of Gender Occupational Selection on Aptitudes with Gender Occupational Segregation

The preceding evidence indicates that males and females select into occupations in ways consistent with research on sex differences in sensory, motor and spatial abilities. We next ask whether this selection has any meaningful implication for the occupational segregation we

[19] We have estimated the models reported in table 6 using the shrinkage estimator Least Absolute Shrinkage and Selection Operator (LASSO). For 1970, the estimates from this method are zero for color vision, manual dexterity and motor coordination. For 2012 the estimates are zero for color vision, near acuity, hearing, manual dexterity, motor coordination and eye-hand-foot coordination. For both years, the estimates for noise, feeling, handling and the spatial measures are mostly modestly smaller that in table 6. These results are available from the authors on request.

observe in the labor market?

In tables 5 and 6, we provide estimates of adjusted Duncan indices following equation (3). These estimates remove the impact of any sex difference in occupational selection on the indicated attribute, all else equal. Table 5 shows the Duncan indices constructed in this way from univariate regressions, while Table 6 shows the effect of eliminating different groups of occupational attributes based on the multivariate regressions.

From an economic standpoint, the changes induced by individually removing the influence of many of the skills is quite small. For 1970 over the sensory and motor attributes the predicted Duncan indices range from 0.610 to 0.651, compared to an actual Duncan index of 0.644 in that year. These represent fluctuations in the index of no more than 5.5%. In 2012, some of these attributes have a larger effect: eliminating selection on hearing, noise, eye-hand-foot coordination or clerical perception would reduce the Duncan index by 7-12%.

The spatial attributes have more traction. The predicted Duncan removing the gender differential in selection on depth perception (which has the more significant effect) is 10.4% lower than the actual Duncan in 1970, and 16.1% lower than the actual in 2012.

Among variables capturing the competing accounts, physical strength and competition have the largest effect on the Duncan index in 1970, each reducing the index by around 5%. In 2012, physical strength, the temperament for dealing with people and mortality risk have the largest effect, in the 4-6% range.

Table 6 shows the results from eliminating the impact of selection on different groups of skills based on the regressions in table 4. The impact of eliminating skill selection in groups is much larger than in the univariate results. In 1970, the effect of eliminating selection on sensory and motor skills is to reduce the Duncan by 4.2% and 5.1% respectively; the effect of eliminating selection on spatial skills is higher, at 10.9%. In 2012, eliminating selection on sensory skills would reduce the Duncan by 7.1%, while eliminating selection on motor skills is 3.3%. Again, spatial skills are quantitatively more important, with a predicted reduction of around 10.4%. In total, eliminating selection on sensory, motor and spatial skills would reduce the Duncan by 20.8% in 1970, and 22.6% in 2012.

The effect of eliminating selection on the variables representing the alternative hypotheses is generally smaller in 1970, ranging from 1.9-3.4%. In total, eliminating selection on these variables controls would reduce the Duncan index by 14.4%. In 2012, the impacts of the different groups ranges from 0-6.3%, with a combined effect of 18.3%.

Eliminating selection on all of the occupational attribute measures reduces the Duncan index to 0.420 in 1970 (a 34.8% reduction) and 0.299 in 2012 (a 41.1% reduction.) Selection on observable occupation attributes therefore accounts for a large portion of occupational segregation, although the majority of the Duncan index remains "unexplained".[20]

VII Implications for the Gender Earnings Gap

We have shown that accounting for differential gender based occupational selection on sensory, motor and spatial occupational aptitudes leads to substantially lower estimated occupational segregation, and that these measures appear to be quantitatively more important than measures of time flexibility, occupational prestige, competition and risk, people/things orientation, language and math skills or physical strength. We next investigate the relationship

[20] The association between the aptitudes we consider and gender based occupational segregation appears fairly constant over time. Estimating adjusted Duncan indices by the age groups 15-24, 25-34 and 35-64 (using the 388 occupations with positive employment for both males and females among all cohorts), we find the relative importance of the sensory, motor and spatial skills remains relatively constant with age, ranging from 16-20% in 1970 and 19-25% in 2012. The effect of the variable representing the alternative accounts, in contrast, diminishes substantially with age. Eliminating selection on these variables reduces the Duncan index by 22% and 28% for the youngest age group in 1970 and 2012, respectively; for the oldest age group, these effects are 11.4% and 15.5% (all underlying results are available from the authors on request).The actual Duncan index rises with age, modestly in 1970 and by around 14% percent in 2012.

between these variables and the gender earnings gap.

In the top panel of Table 7 we present the analysis for 2012 using equation (4). The results in this table are based on the estimates in table 4. The male/female earnings gap in all occupations was just under $14,000 (in 2002 constant dollars), of which 32.4% was due to differences in the distribution of men and women across occupations.[21] In the next row we normalize the results to the 468 occupations we use in the Duncan analysis. The overall wage gap within these occupations is identical to that in the full set of occupations, and the proportion accounted for by occupational segregation is very similar as well, at 32.5%.

In the next panel we calculate the wage gap using the predicted distributions of men and women across occupations, after negating selection on specific groups of aptitudes. The wage gap *increases* negating selection on sensory and motor skills, indicating that women's skill profile is relatively advantaged in these dimensions. Eliminating selection on spatial skills has the opposite effect, although the decline in the earnings gap is very small at around $200. This is mainly accounted for by a decline in the within-occupation component, indicating that eliminating selection on spatial skills would not necessarily push women into higher paying occupations overall, but would push them into occupations where the male-female earnings gap was smaller. Eliminating selection on all sensory, motor and spatial skills leads to an increase in the overall gender wage gap of around $1,300.

Although the variables representing competing hypothesis have a smaller impact on gender segregation than the sensory, motor and spatial skills, their effect on the gender wage gap is generally larger. The impact of eliminating selection on people/things orientation and physical strength, like the results for sensory, motor and physical strength leads to a larger gap and cross

[21] The results are very similar if we use the alternative decomposition in which the difference in the occupational shares are weighted by female wages.

occupation component. However, eliminating selection on cognitive attributes, job flexibility and most notably occupational prestige, mortality risk and competition significantly lowers the cross occupation component. The results for risk and cognitive skills are particularly striking. The total effect on the gender wage gap would be to reduce it by around $4,100, or 30%. Although these variables have relatively small impacts on occupational segregation a strong wage gradient means that these small impacts have relatively large consequences for men and women's wages. On net, eliminating selection on the entire set of these variables would result in a slightly lower gender wage gap, at $13,270.

Of course these simulated impacts are contingent on a set of skill prices specific to time and place. It is necessarily true that as within occupation wage gaps fall, all else equal the cross occupation gap will account for a larger proportion of the overall gender wage gap. In addition, as long as men and women remain significantly segregated in employment, the size of the cross occupation component, and our simulated impact of eliminating occupational selection on skills, will be responsive to changes the underlying constellation of skill prices.

In the second panel of Table 7 we present corresponding results for 1970. The overall wage gap is higher in 1970, at $20,704, primarily due to a larger within occupation component. The contribution of cross occupation differences is smaller (21.0%). Among the 468 occupations that we examine, these figures are $20,608 and $20.9%, respectively. Relative to the results for 2012, eliminating the selection on our sensory, motor and spatial attributes now reduces the cross occupation component and the overall gap. Eliminating selection on people/things orientation and physical strength again increases the cross occupation component although in proportionate terms less than in 2012. Finally the eliminating selection on the remaining attributes lowers the cross occupation component although not as dramatically as in 2012.

VIII Conclusions

Research from a number of fields indicates that males and female differ, on average, in a number of sensory, motor and spatial aptitudes that are potentially important for occupational choice. We bring these findings to the puzzle of persistent gender based occupational segregation in the US labor market. Our results suggest that males and females select into occupations in ways predicted by this research. For example, males have been found to have a higher tolerance of noise and are found disproportionately in noisy occupations. We simulate that occupational segregation is higher than it would otherwise be as a result of this selection. Conditional on our mapping of the research on sex differences in aptitudes into DOT occupational attributes, in both 1970 and 2012, absent this selection the Duncan index of occupational segregation would be, all else equal, 20-23 percent lower than its observed level.

We also compare the quantitative importance of these variables to a set of variables intended to capture competing hypotheses of the sources of gender segregation. While we find that some of these alternative hypotheses do account for gender segregation, they are generally less important quantitatively than our measures of sensory, motor and spatial skills. Gender differences in spatial skills in particular appear to have an important impact on gender segregation: eliminating selection on these skills alone would, all else equal, reduce the Duncan index by around 10% in both 1970 and 2012.

We should note that these comparisons are contingent on the ability of the DOT data to capture the different explanations of gender based occupational segregation. One might argue that the inability of these variables to perfectly capture different aspects of occupations biases our results against finding an impact of a given explanation. We would note that the DOT variables were not developed with the specific aim of evaluating any of the explanations we consider, although they clearly capture some salient dimensions of each. Furthermore, we argue the first message of the analysis is the importance of gender differences in sensory, motor and especially spatial aptitudes for occupational segregation, all skills that have been typically ignored in economic research in this area.

Operationalizing these findings in a policy context depends on discovering the sources of the gender differences in these aptitudes. For example the response to aptitude differentials due to biology or very slow changing environmental stimuli in early childhood might differ from the response to differentials due to environmental and institutional factors that are a function of place and time. The answer to this question is being actively pursued in a number of fields.[22]

The findings also highlight a lesson from the literature on these sex differences for research on the task content of jobs. The choice of specific DOT or O*NET skills to represent specific tasks may not be innocuous, particularly if differences across genders are to be compared or contrasted.[23]

In their recent study of gender occupational segregation Blau et al. (2013) observe that for significant desegregation in the future, "women would need to begin to make significant inroads into areas where they have not so far, especially predominantly male blue-collar jobs, and continue to build on their gains in STEM fields; and/or men would need to enter predominantly female occupations in much larger numbers than they have in the past" (p. 490). Our results point to some hypotheses of why these inroads are yet to be made.

[22] Baker and Cornelson (2016) investigate how the increase is females' sports participation due to Title IX affected the spatial content of female employment.

[23] For example the DOT aptitudes Finger Dexterity (a fine motor skill) and Eye-Hand-Foot coordination (a gross motor skill) are used to represent routine and non routine manual skills respectively in the Autor et al. (2003) taxonomy of tasks. These skills are shown in tables 2-4 to have strong relationships with the log odds of male employment, particularly when used in isolation. Correspondingly, Autor and Price (2013) report persistent gender gaps between 1960 and 2010 in both routine and non routine manual skills employment using this taxonomy. In contrast Black and Spitz-Oener (2010) report large changes in the gender differences between 1979 and 1999 in routine and non routine manual tasks for West Germany using broader definitions of the associated aptitudes and activities.

References

Abramov, Israel, Gordon, James, Feldman, Olga and Alla Chavarga, (2012a) "Sex & Vision I: Spatio-temporal Resolution" *Biology of Sex Differences*, 3(1) 20

Abramov, Israel, Gordon, James, Feldman, Olga and Alla Chavarga, (2012b) "Sex and Vision II: Color Appearance of Monochromatic Lights" *Biology of Sex Differences*, 3(1) 21.

Akerlof, George A. and Rachel E. Kranton**.** **(**2000) "Economics and Identity." *Quarterly Journal of Economics*. August, 105: 3, pp. 715–53.

Autor, David H., Frank Levy, and Richard J. Murnane. (2003) "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics*, 118(4) 1279-1333.

Autor, David H and Breden Pruice, (2013) "The Changing Task Composition of the US Labor Market: An Update of Autor, Levy and Murname (2003)", mimeo MIT.

Auyeung Bonnie, Knickmeyer, Rebecca, Ashwin, Emma, Taylor, Kevin, Hackett, Gerald and Simon Baron-Cohen et al. (2011) "Effects of Fetal Testosterone on Visuospatial Ability", *Archives of Sexual Behavior*, 41 (2012), 571–581.

Bacolod, Marigee and Bernardo S. Blum (2010). "Two Sides of the Same Soin: U.S. "Residual" Inequality and the Gender Gap." *Journal of Human Resources* 45(1): 197-242.

Baker, Michael and Kirsten Cornelson, (2016), "Title IX and the Spatial Content of Female Employment—Out of the Lab and into the Labor Market**"** *NBER Working Paper* no. 22641.

Bielby, William T. and James N. Barron (1986). "Men and Women at Work: Sex Segregation and Statistical Discrimination." *American Journal of Sociology*, 91(4) 759-799.

Black, Sandra and Alexandra Spitz-Oener, (2010.) "Explaining Women's Success: Technological Change and the Skill Content of Women's Work." *The Review of Economics and Statistics* 92(1) 187-194.

Blau, Francine D. and Lawrence M. Kahn (2000), "Gender Differences in Pay", *Journal of Economic Perspectives*, 14(4) 75–99.

Blau, Francine D. and Lawrence M. Kahn (2006), "The U.S. Gender Pay Gap in the 1990's: Slowing Convergence", *Industrial and Labor Relations Review* 60(1) 45-66.

Blau, Francine D., Brummund, Peter and Albert Yung-Hsu Liu (2013), "Trends in Occupational Segregation by Gender 1970–2009: Adjusting for the Impact of Changes in the Occupational Coding System", *Demography* 50, 471–492

Blau Weiskoff, Francine, (1972) "'Women's Place' in the Labor Market", *American Economic Review,* 62(1/2) 161-166.

Bonin, Holger, Thomas Dohman, Armin Falk, David Huffman and Uwe Sunde (2007). "Cross-sectional Earnings Risk and Occupational Sorting: the Role of Risk Attitudes." *Labour Economics* 14: 926-937.

Borghans, Lex, Ter Weel, Bas and Bruce A. Weinberg, (2014) "People Skills and the Labor-Market Outcomes 'of' Underrepresented Groups", *Industrial and Labor Relations Review* 67(2) 287-334.

Brand, Gérard and Jean-Louis Millot (2001) "Sex Differences in Human Olfaction: Between Evidence and Enigma", *The Quarterly Journal of Experimental Psychology Section B: Comparative and Physiological Psychology*, 54(3), 259-270

Brizendine, Louann, (2007) *The Female Brain* New York: Bantam.

Bureau of Labor Statistics (2015). "Highlights of Women's Earnings in 2014, November." Report 1058.

Burns, Nicholas R, and T Nettelbeck, (2005) "Inspection Time and Speed of Processing: Sex Differences on Perceptual Speed but not IT" *Personality and Individual Differences* 39 (2), 439-446.

Buser, Thomas, Muriel Niederle and Hessel Oosterbeek (2014). "Gender, Competitiveness and Career Choices." *Quarterly Journal of Economics* 129(3): 1409-1447.

CANSIM, Statistics Canada, Ottawa, accessed December 3, 2015.

Cherney Isabelle D. and Daniel Voyer (2010) "Development of a Spatial Activity Questionnaire I: Items Identification" *Sex Roles* 62 89-99.

Cotton, Christopher, Frank McIntyre and Joseph Price (2013). "Gender Differences in Repeated Competition: Evidence from School Math Contests." *Journal of Economic Behavior and Organization* 86: 52-66.

Croson, Rachel and Uri Gneezy (2009). "Gender Differences in Preferences." *Journal of Economic Literature* 47(2): 448-474.

DeLeire, Thomas and Helen Levy (2004). "Worker Sorting and Risk of Death on the Job." *Journal of Labor Economics* 22(4): 925-953.

Dickens, W.T, and J.R. Flynn (2001), "Heritability Estimates Versus Large Environmental Effects: The IQ Paradox Resolved," *Psychological Review*, Vol. 108, No. 2, pp. 346-369.

Eckel, Catherine C., and Philip J., Grossman (2008) "Differences in the Economic Decisions of Men and Women: Experimental Evidence." In: Plott, Charles, Smith, Vernon (Eds.), *Handbook of Experimental Economics Results*, vol. 1. Elsevier, New York.

Ellison, Glenn and Ashley Swanson (2010). "The Gender Gap in Secondary School Mathematics at High Achievement Levels: Evidence from the American Mathematics Competitions." *Journal of Economic Perspectives*, 24(2): 109-128.

Falter, C.M., Arroyo, M., and G.J Davis, (2006) "Testosterone: Activation or Organization of Spatial Cognition?", *Biological Psychology* 73, 132-140.

Fine, Cordelia (2010) *Delusions of Gender: How Our Minds, Society and Neurosexism Create a Difference.* New York: W.W. Norton Company; 2010.

Gilligan, Carol (2001). *In a Different Voice: Psychological Theory and Women's Development.* Cambridge, MA: Harvard University Press.

Gneezy, Uri, Niederle, Muriel, Rustichini, Aldo, 2003. "Performance in Competitive Environments: Gender Differences." *Quarterly Journal of Economics*. 118, 1049–1074.

Goldin, Claudia (2013) "A Pollution Theory of Discrimination: Male and Female Differences in Occupations and Earnings", Harvard University.

Goldin, Claudia (2014), "A Grand Gender Convergence: Its Last Chapter", *American Economic Review*, 104(4) 1091-1119.

Goldin, Claudia and Cecilia Rouse (2000). "Orchestrating Impartiality: the Impact of "Blind" Auditions on Female Musicians." *Quarterly Journal of Economics* 90(4): 715-741.

Grazier, S. and P.J. Sloane (2008). "Accident Risk, Gender, Family Status and Occupational Choice in the UK." *Labour Economics* 15(5): 938-957.

Gross, Edward (1968). "Plus Ça Change,,,? The Sexual Structure of Occupations Over Time." *Social Problems* 16 (2): 198-208.

Hall, J.A.Y. and D Kimura (1995) "Sexual Orientation and Performance on Sexually Dimorphic Motor Tasks", *Archives of Sexual Behavior* 24(4) 395-407.

Halpern, Diane F. (2012), *Sex Differences in Cognitive Abilities*: 4th Edition, New York, NY: Psychology Press.

Handa, Robert J. and Robert F. McGivern (2015) Steroid Hormones, Receptors, and Perceptual and Cognitive Sex Differences in the Visual System, Current Eye Research, 40:2, 110-127

Hedges, Larry V. and Amy Nowell (1995). "Sex Differences in Mental Test Scores, Variability and Numbers of High-scoring Individuals." *Science* 269 (5220): 41-45.

Hyde, Jane Shibley, (2014) "Gender Similarities and Differences" *Annual Review of Psychology*, 65(3) 373-398.

Krueger, Alan B. and David Schkade (2008). "Sorting in the Labor Market: do More Gregarious Workers Flock to Interactive Jobs?" *Journal of Human Resources* 43(4): 859-883.

Leeth, John D. and John Ruser (2006). "Safety Segregation: the Importance of Gender, Race, and Ethnicity on Workplace Risk." *Journal of Economic Inequality* 4(2): 123-152.

Levanon, Asaf and David B. Grusky, (2012) "Why is Gender Segregation So Extreme?" Stanford Center on Poverty and Inequality.

Lippa, Richard A., Collaer, Marcia L. Michael Peters (2008) "Sex Differences in Mental Rotation and Line Angle Judgments Are Positively Associated with Gender Equality and Economic Development Across 53 Nations", *Archives of Sexual Behavior*, 39, 990–997.

Lordan, Grace and Jorn-Steffen Pischke (2016) "Does Rosie Like Riveting? Male and Female Occupational Choices", NBER Working Paper #22495 .

Maccoby, Eleanor G., and Carol N. Jacklin. 1974. *The Psychology of Sex Differences*. Stanford, Calif.: Stanford University Press.

Macpherson, David, and Barry T. Hirsch, (1995) "Wages and Gender Composition: Why Do Women's Jobs Pay Less?" Journal of Labor Economics 13 426–71.

Mercer, Michele E., Suzanne C. Drodge, Mary L. Courage and Russell J. Adams (2014), "A Pseudoisochromatic Test of Color Vision for Human Infants", *Vision research*, 100, 72-77.

McCarthy, Margaret N. and Gregory F. Ball, (2011) "Tempests and Tales: Challenges to the Study of Sex Differences in the Brain", *Biology of Sex Differences*, 2(4)

McFadden, Dennis, (1998) "Sex Differences in the Auditory System", *Developmental Neuropsychology*, 14(2/3) 261-298.

McFadden, Dennis, (2002) "Masculinization Effects in the Auditory System", *Archives of Sexual Behavior*, 31(1) 99–111.

McFadden, Dennis, (2008) "Masculinization of Mammalian Cochlea", *Hearing Research*, 252, 37-48.

Miller, David I. and Diane F. Halpern, (2013), "Can Spatial Training Improve Long-term

Outcomes for Gifted STEM Undergraduates*?", Learning and Individual Differences*, 26 141-152.

Miller, David I. and Diane F. Halpern, (2014), "The New Science of Cognitive Sex Differences." *Trends in Cognitive Sciences* 18(1), 37-45

Murray IJ, Parry NR, McKeefry DJ, and A. Panorgias (2012), "Sex-Related Differences in Peripheral Human Color Vision: a Color Matching Study" *Journal of Vision* 12(1)

Moore DS, Johnson SP. (2008) "Mental Rotation in Human Infants" *Psychological Science* 19:1063–66.

Newcombe, Nora S, (2010), "On Tending to our Scientific Knitting: Thinking about Gender in the Context of Evolution". In J. Chrisler and D. McCreary (Eds.), *Handbook of gender research in psychology*, Springer, 259-274.

Nicholson KG, and D. Kimura (1996) "Sex Differences for Speech and Manual Skill" *Perceptual and Motor Skills* 82, 3–13.

Niederle, Muriel and Lise Vesterlund (2007). "Do Women Shy Away from Competition? Do Men Compete too Much?" *Quarterly Journal of Economics* 122(3): 1067-1101.

Office for National Statistics, (2015) "Annual Survey of Hours and Earnings, 2015 Provisional Results, November 18, 2015

Pan, Jessica (2015), "Gender Segregation in Occupations: The Role of Tipping and Social Interactions", *Journal of Labor Economics*, 33(2), 365-408.

Peters, M., Servos, P., & Day, R. (1990). "Marked Sex Differences on a Fine Motor Skill Task Disappear when Finger Size is used as a Covariate" *Journal of Applied Psychology*, 75(1), 87–90.

Peters, M., & Campagnaro, P. (1996). "Do Women Really Excel over Men in Manual Dexterity?" *Journal of Experimental Psychology: Human Perception and Performance*, 22(5), 1107–1112.

Peters, Ryan M., Hackeman, Erik and Daniel Goldreich (2009) "Diminutive Digits Discern Delicate Details: Fingertip Size and the Sex Difference in Tactile Spatial Acuity", *The Journal of Neuroscience*, 29(50),15756 –15761

Pinker, Susan (2008). *The Sexual Paradox: Men, Women and the Real Gender Gap.* New York: Macmillan.

Polachek, Solomon William, (1981) "Occupational Self-Selection: A Human Capital Approach to Sex Differences in Occupational Structure", *The Review of Economics and Statistics*, 63(1) 60-69.

Quinn PC, and LS. Liben (2008). “A Sex Difference in Mental Rotation in Young Infants.” *Psychological Science* 19: 1067–70

Roivainen, Eka (2011) “Gender Differences in Processing Speed: A Review of Recent Research.” *Learning and Individual Differences* 21: 145–149

Riach, Peter A. and Judith Rich (2002). “Field Experiments of Discrimination in the Market Place.” *Economic Journal* 112(483): F480-F518.

Riach, Peter A. and Judith Rich (2006). “An Experimental Investigation of Sexual Discrimination in Hiring in the English Labor Market.” *B.E. Journal of Economic Analysis and Policy: Advances in Economic Analysis and Policy* 6(2): 1-20.

Sanders, Geoff (2013) “Sex Differences in Motor and Cognitive Abilities Predicted from Human Evolutionary History with Some Implications for Models of the Visual System”, *The Journal of Sex Research*, 50:3-4, 353-366.

Sanders, Geoff., and Kadam, A. (2001), “Prepubescent Children Show the Adult Relationship between Dermatoglyphic Asymmetry and Performance on Sexually Dimorphic Tasks”. *Cortex*, 37, 91-100.

Sanders, Geoff., and Perez, M. (2007). Sex differences in performance with the hand and arm in near and far space: A possible effect of tool use. *Evolutionary Psychology, 5,* 786-800.

Sanders, Geoff., and Walsh, T. (2007). Testing predictions from the hunter-gatherer hypothesis – 1: Sex differences in the motor control of hand and arm. *Evolutionary Psychology, 5,* 653-665.

Sanders, Geoff, Kamila Sinclair, and Tom Walsh, (2007a) “Testing Predictions from the Hunter-Gatherer Hypothesis – 1: Sex Differences in the Motor Control of hand and Arm”, *Evolutionary Psychology*, 5(3): 653-665.

Sanders, Geoff, Kamila Sinclair, and Tom Walsh, (2007b) “Testing Predictions from the Hunter-Gatherer Hypothesis – 2: Sex Differences in the Visual Processing of Near and Far Space”, *Evolutionary Psychology*, 5(3): 666-679.

Spelke, Elizabeth S. (2005) “Sex Differences in Intrinsic Aptitude for Mathematics and Science? A Critical Review”, *American Psychologist*, 60(9) 950-958.

Stancy, Helen and Mark Turner, (2010), “Close Women, Distant Men: Line Bisection reveals Sex-Dimorphic Patterns of Visuomotor Performance in Near and Far Space”, *British Journal of Psychology*, 101(2), 293–309.

Su, Rong, James Rounds and Patrick Ian Armstrong (2009). “Men and Things, Women and People: a Meta-Analysis of Sex Differences in Interests.” *Psychological Bulletin* 135(6):

859-884.

U.S. Department of Commerce (2011) "Women in STEM: A Gender Gap to Innovation", ESA Issue Brief #04-11, August.

U.S. Department of Labor Employment and Training Administration (1991), *The Revised Handbook for Analyzing Jobs*, Washington D.C.

Velle, Weiert, (1987), "Sex Differences in Sensory Functions", *Perspectives in Biology and Medicine*, 30(4), 490-522.

Ward, P., Farrow, D., Harris, K.R., Williams, A.M., Eccles, D.W. and, K.A. Ericsson, (2008), "Training Perceptual-Cognitive Skills: Can Sport Psychology Research Inform Military Decision Training?" *Military Psychology* 20, S71-S102.

Watson, N.V., and Kimura, D. (1991). "Non-Trivial Sex Differences in Throwing and Intercepting: Relation to Psychometrically-Defined Spatial Functions". *Personality and Individual Differences, 12,* 375-385.

Weinberg, Bruce, Bas ter Weel and Lex Borghans (2008). "Interpersonal Style and Labor Market Outcomes." *Journal of Human Resources* 43(4): 815-858.

Weinberger, Catherine J. (1999). "Mathematics Test Scores, Gender, Race, Ethnicity and the Science and Engineering Workforce." Unpublished Manuscript, University of California, Santa Barbara.

Weinberger, Catherine J. (2001). "Is Teaching More Girls More Math the Key to Higher Wages?" Chapter 11 in *Squaring Up: Policy Strategies to Raise Women's Incomes in the United States,* ed. Mary C. King. University of Michigan Press.

Weinberger, Catherine, (2014). "The Increasing Complemetarity between Cognitive and Social Skills", *Review of Economics and Statistics* 96(5), 849-861.

Xie, Yu and Kimberlee A. Shauman (2003). *Women in Science: Career Processes and Outcomes.* Harvard University Press.

Appendix

Table A1 – DOT and O*NET measures of sensory, motor and spatial skills and aptitudes

DOT measure(s) (type)	Scale	Expected coefficient on "male"	Description**	Occupations with highest/lowest rating
Color discrimination (aptitude)	1 to 5*	-	"The ability to match or discriminate between colors in terms of hue, saturation, and brilliance. Ability to identify a particular color combination from memory and to perceive contrasting color combinations."	Misc. personal appearance workers/ boilermakers
Color vision (physical demand)	0 to 3	-	"Ability to identify and distinguish colors"	Motion picture projectionists/ mathematicians
Near visual acuity (physical demand)	0 to 3	-	"Clarity of vision at 20 inches or less."	Tellers/ dancers and choreographers
Far visual acuity (physical demand)	0 to 3	+	"Clarity of vision at 20 feet or more"	Bus drivers/ lawyers
Hearing (physical demand)	0 to 3	-	"Perceiving the nature of sounds by ear."	Lawyers/ dancers and choreographers
Noise (environmental condition)	1 to 5	+	"The noise intensity level to which the worker is exposed in the job environment"	Misc. construction operators/ chiropractors
Taste/smell (physical demand)	0 to 3	-	"Distinguishing, with a degree of accuracy, differences or similarities in intensity or quality of flavors or odors, or recognizing particular flavors or odors, using tongue or nose."	Meter readers, utilities/ plasterers and stucco masons
Feeling (physical demand)	0 to 3	-	"Perceiving attributes of objects, such as size, shape, temperature, or texture, by touching with skin, particularly that of fingertips."	Chiropractors/ actuaries

Finger dexterity (aptitude)	1 to 5*	-	"The ability to move the fingers and manipulate small objects with the fingers rapidly or accurately."	Dentists/ clergy
Fingering (physical demand)	0 to 3	-	"Picking, pinching, or otherwise working primarily with fingers rather than with the whole hand or arm as in handling."	Tellers/ dancers and choreographers
Motor coordination (aptitude)	1 to 5*	_	"The ability to coordinate eyes and hands or fingers rapidly and accurately in making precise movements with speed. Ability to make a movement response accurately and swiftly"	Dancers and choreographers/ meter readers, utilities
Eye-hand-foot coordination (aptitude)	1 to 5*	+	"The ability to move the hand and foot coordinately with each other in accordance with visual stimuli."	Dancers and choreographers/ boilermakers
Clerical perception (aptitude)	1 to 5*	-	"The ability to perceive pertinent detail in verbal or tabular material. Ability to observe differences in copy, to proofread words and numbers, and to avoid perceptual errors in arithmetic computation. A measure of speed of perception is required in many industrial jobs even when the job does not have verbal or numerical content."	Computer programmers/ pressers, textile, garment and related materials
Manual dexterity (aptitude)	1 to 5*	?	"The ability to move the hands easily and skillfully. Ability to work with the hands in placing and turning motions…manual dexterity involves working with the arms and hands…Finger movements may or may not accompany the exercise of manual dexterity."	Veterinarians/ meter readers, utilities
Handling (physical demand)	0 to 3	-	"Seizing, holding, grasping, turning, or otherwise working with hand or hands."	Optometrists/ dancers and choreographers

Spatial (aptitude)	1 to 5*	+	“The ability to think visually of geometric forms and to comprehend the two-dimensional representation of three-dimensional objects. The ability to recognize the relationships resulting from the movement of objects in space.”	Optometrists/ insurance sales agents
Depth perception (physical demand)	0 to 3	+	“Three-dimensional vision. Ability to judge distances and spatial relationships so as to see objects where and as they actually are.”	Bus drivers/ sociologists
Other Aptitudes and Attributes				
GED language	1 to 5		“…though language courses follow a…pattern of progression in primary and secondary school, particularly in learning and applying the principles of grammar, this pattern changes at the college level. The diversity of language courses offered at the college level precludes the establishment of distinct levels of language progression for these four years. Consequently, language development is limited to five defined levels of GED.”	Clergy/ parking lot attendants
GED math	1 to 6		“The description of the various levels of language and mathematical development are based on the curricula taught in schools throughout the United States. An analysis of mathematics courses in school curricula reveals distinct levels of progression in the primary and secondary grades and in college. These levels of progression facilitated the selection and assignment of six levels of GED for the mathematical development scale.”	Mathematicians/ parking lot attendants
Temperament – dealing with people	0 to 1		“…interpersonal relationships in job situations beyond receiving work instructions.”	Recreational therapists/ dancers and choreographers

Interests - things	0 to 1	"Things Functions can be divided into relationships based upon the worker's involvement with either machine and equipment (machine related) or with tools and work aids (non-machine related)...Things Functions also represent levels of complexity based on the worker's decisions or judgements."	Parking lot attendants/ audiologists
Physical strength	1 to 5	"This factor is expressed by one of five terms: Sedentary, Light, Medium, Heavy and Very Heavy"	Therapists, all other / statisticians
Level of competition	1 to 5	To what extent does this job require the worker to compete or to be aware of competitive pressures?	Photographers/Crossing Guards
Time pressure	1 to 5	How often does this job require the worker to meet strict deadlines?	Plating and Coating Machine Setters, Operators, and Tenders, Metal and Plastic/Bartenders
Structured vs. unstructured work	1 to 5	To what extent is this job structured for the worker, rather than allowing the worker to determine tasks, priorities, and goals? (Note: higher values imply more freedom for the worker)	Chiropractors/Telephone operators
Freedom to make decisions	1 to 5	How much decision making freedom, without supervision, does the job offer?	Gaming managers/Graders and Sorters, Agricultural Products

* Reverse coded in original data; re-labelled to be in increasing order of skill. ** Source—US Department of Labor (1991).

Data Methods

Converting Census data into 2000 Census occupation codes

In our analysis, we use the 1% Census samples provided by the IPUMS website, as well as the 2012 three-year ACS. We restrict the sample to 18-64 year olds who are employed in the civilian labor force, with non-allocated occupation codes.

To ensure comparability with previous work on occupational segregation, we use the 2000 Census occupation codes throughout our analysis. To convert the 1970 Census data to the year 2000 codes, we follow the procedure outlined in Blau et al. (2013). We start by converting the 1970 data to 1980 codes using the gender-specific crosswalk provided by the Census Bureau (available on IPUMS at https://usa.ipums.org/usa/resources/chapter4/occ_70-80.pdf). There were minimal changes between the 1980 and 1990 coding systems. For 1980 occupations that were combined into a single 1990 occupation (six pairs), we simply add the number of men/women in each 1980 occupation to arrive at the 1990 total. For the 1980 occupations that were split in the 1990 coding system, we redistribute the number of 1980 incumbents into the 1990 codes based on the distribution of employment in 1990. Finally, we use the crosswalk developed by Blau et al. (2013) to convert the data into the 2000 Census codes.

The 2012 ACS occupation codes are similar to those used in the 2000 Census. For the occupations that did experience changes from the 2000 Census to the ACS, we follow a procedure that is similar to that used in converting the 1980 data to 1990 codes.

Converting DOT data to 2000 Census occupation codes

The DOT77 data was obtained from a 1971 CPS file, augmented with DOT ratings, which is available from the ICPSR website. This file contains both the DOT occupational coding and the 1970 census occupational coding. Because each 1970 occupation contains several DOT occupations, we calculate the DOT rating for each 1970 occupation using an employment-weighted mean. We use procedures similar to that described in the Census data to convert the ratings to the 2000 Census occupation coding, taking employment-weighted means at each step. Note that the crosswalks used in this process are not gender specific; each 2000 Census occupation is given a single DOT rating, not a separate rating for men and women.

The DOT91 data was also obtained from the ICPSR website. DOT91 ratings are only available for the 1991 DOT occupational coding. Most occupations had the same coding in 1977 and 1991. A list of exceptions was available in the ICPSR documentation, which was used to convert the remaining occupations (do-files available upon request.) Once the data was consistent with the 1977 coding system, the 1991 data was merged onto the 1971 CPS file, and was then converted to the 2000 Census codes in the same was as the 1977 data.

There are 505 occupations in the 2000 occupation coding system. Of these, 478 had non-zero employment for both men and women, in both 1970 and 2012. Another 2 occupations could not be matched to the DOT data, resulting in a sample of 476 occupations that could be matched to the DOT data.

*Converting O*NET and fatalities data to 2000 Census occupation codes*

The O*NET and Census of Fatal Injuries data are provided at the SOC occupation level. To convert these to Census Occupational Coding, we use the crosswalk provided by IPUMS. 494 Census occupations could be linked to the O*NET data; of these, 468 overlap with the DOT data and have non-zero employment for both men and women in both years. These 468 occupations represent our final sample.

Table A2- Sensitivity Analysis- Changes in the specification occupational skills and attributes

Alternative specification	**Results (Based on the full specification with all variables.)**
Controlling for the ratio of wages and hours worked	The results are similar. Adding these to the controls, the predicted Duncan indices (negating selection on all attributes) are 0.410 and 0.292, compared to 0.420 and 0.299 in our main analysis.
Using only one of color discrimination or color vision	The results are similar if we drop either of these variables. The predicted Duncan index ranges from 0.418-0.424 in 1970 and from 0.297-0.299 in 2012, depending on the combination used.
Using only one of fingering or finger dexterity	The results are similar if we drop either of these variables. The predicted Duncan index ranges from 0.419-0.422 in 1970 and from 0.299-0.304 in 2012, depending on the combination used
Using only one of finger dexterity or motor control	The results are similar if we drop either of these variables. The predicted Duncan index ranges from 0.418-0.422 in 1970 and from 0.299-0.304 in 2012, depending on the combination used.
Using only one of manual dexterity or motor control.	The results are similar if we drop either of these variables. The predicted Duncan index ranges from 0.418-0.422 in 1970 and from 0.298-0.299 in 2012, depending on the combination used.
Controlling for alternative measures of the social skill of employment—DOT interests “activities involving contact with people”, and O*NET work context “contact with others”	Using the “interests – activities involving contact with people” measure results in a Duncan index of 0.420 in 1970 and 0.300 in 2012. Using the O*NET work context “contact with others” results in a Duncan index of 0.420 in 1970 and 0.300 in 2012.
Alternative specification	**Results (Based on the full specification with all variables.)**
Switching to 1991 DOT definitions for both years	The only variable that changes significance is tasting-smelling, which would not have been significant in 1970 if the 1991 definitions had been used. If 1991 definitions are used, the predicted Duncan index (negating selection on all occupational attributes) becomes 0.414 in 1970, as opposed to 0.420 in our main analysis.
Switching to 1977 DOT definitions for both years	The coefficient on clerical perception becomes larger and significant at the 5% level in 2012 if the 1977 definitions are used; the coefficient on eye-hand-foot coordination becomes smaller and insignificant. All other coefficients remain of similar magnitudes. If 1977 definitions are used, the predicted Duncan index (negating selection on all occupational attributes) becomes 0.295 in 2012, as opposed to 0.299 in our main analysis.

Table 1: Gender based occupational segregation in the US labor market

	1970	1980	1990	2000	2012
Duncan Index	0.644	0.586	0.540	0.519	0.506
Top 5 Occupations	Secretaries and administrative assistants	Secretaries and administrative assistants	Secretaries and administrative assistants	Secretaries and administrative assistants	Secretaries and administrative assistants
	Driver/sales workers and truck drivers	Driver/sales workers and truck drivers	Driver/sales workers and truck drivers	Driver/sales workers and truck drivers	Registered nurses
	Elementary and middle school teachers	Bookkeeping, accounting and auditing clerks	Elementary and middle school teachers	Registered nurses	Driver/sales workers and truck drivers
	Bookkeeping, accounting and auditing clerks	Elementary and middle school teachers	Registered nurses	Elementary and middle school teachers	Elementary and middle school teachers
	Maids and housekeeping cleaners	Registered nurses	Bookkeeping, accounting and auditing clerks	Bookkeeping, accounting and auditing clerks	Nursing, psychiatric and home health aids
% of Duncan Accounted by top 5 Occupations	13.3	12.5	11.5	9.3	8.8
% of Duncan Accounted by STEM Occupations	2.5	2.3	2.4	2.7	2.6
Total Number of Occupations	505	505	505	505	505
Number of Occupations that account for 50% of the Duncan	25	26	28	31	31
Number of Occupations that account for 90% of the Duncan	166	172	177	176	172

Notes: Authors' calculations from 1970-2000 censuses and 2012 American Community Survey.

Table 2: The relationship between the log odds ratio of male to female employment and measures of physical strength, language and math, people and things, occupational prestige, mortality risk and competitiveness, and time pressure, work structure and decision structure; univariate regressions

		1970		2012	
	Sign	Coefficient	R^2	Coefficient	R^2
Physical strength	+	0.728*** (0.084)	0.137	0.996*** (0.067)	0.319
GED - language	-	-0.091 (0.091)	0.002	-0.505*** (0.078)	0.082
GED – math	+	0.226** (0.090)	0.013	-0.171** (0.081)	0.009
Temperament - people	-	-0.714*** (0.084)	0.132	-0.946*** (0.069)	0.287
Interest - things	+	0.747*** (0.084)	0.145	0.863*** (0.071)	0.239
Occupational prestige	+	0.127 (0.091)	0.004	-0.238*** (0.081)	0.018
Mortality risk	+	0.560*** (0.087)	0.081	0.602*** (0.079)	0.116
Competition	+	0.457*** (0.089)	0.054	0.321*** (0.080)	0.033
Time pressure	+	0.253*** (0.090)	0.017	0.228*** (0.081)	0.017
Structured/unstructured work	+	0.044 (0.091)	0.001	-0.240*** (0.081)	0.019
Freedom to make decisions	+	0.213** (0.091)	0.012	0.064 (0.082)	0.001

Notes: Authors' calculations from 1970 census and 2012 American Community Survey. Each estimate is from a separate regression of the log odds ratio of male to female employment at the occupational level on the indicated skill or aptitude. ***, ** and * indicate statistical significance at the 10, 5, and 1 percent levels respectively.

Table 3: The relationship between the log odds ratio of male to female employment and measures of sensory, motor and spatial skills; univariate regressions

			1970		2012	
		Sign	Coefficient	R^2	Coefficient	R^2
Sensory	Color discrimination	-	0.157* (0.091)	0.007	0.180** (0.081)	0.010
	Color vision	-	0.450*** (0.089)	0.052	0.349*** (0.080)	0.040
	Near acuity	-	-0.173* (0.091)	0.008	-0.230*** (0.082)	0.017
	Far acuity	+	0.594*** (0.087)	0.091	0.471*** (0.078)	0.071
	Hearing	-	-0.542*** (0.088)	0.077	-0.800*** (0.073)	0.205
	Noise	+	0.951*** (0.080)	0.234	1.170*** (0.061)	0.440
	Tasting-smelling	-	-0.070 (0.091)	0.001	-0.037 (0.081)	0.000
	Feeling	-	-0.154* (0.091)	0.006	-0.132 (0.081)	0.006
Motor	Fingering	-	-0.404*** (0.090)	0.042	-0.244*** (0.081)	0.019
	Finger Dexterity	-	-0.148 (0.091)	0.006	-0.064 (0.081)	0.001
	Handling	-	-0.020 (0.091)	0.000	0.277*** (0.081)	0.025
	Manual dexterity	?	0.452*** (0.089)	0.053	0.672*** (0.076)	0.145
	Motor Co-ordination	-	0.153* (0.091)	0.006	0.336*** (0.080)	0.036
	Eye-Hand-Foot	+	0.659*** (0.086)	0.113	0.736*** (0.074)	0.174
	Clerical Perception	-	-0.543*** (0.088)	0.076	-0.855*** (0.072)	0.235
Spatial	Spatial skills	+	0.908*** (0.081)	0.214	0.685*** (0.075)	0.150
	Depth perception	+	1.052*** (0.077)	0.286	1.138*** (0.062)	0.416

Notes: Authors' calculations from 1970 census and 2012 American Community Survey. Each estimate is from a separate regression of the log odds ratio of male to female employment at the occupational level on the DOT measure of the indicated skill or aptitude. ***, ** and * indicate statistical significance at the 10, 5, and 1 percent levels respectively.

Table 4: The relationship between the log odds ratio of male to female employment occupational skills, aptitudes and attributes; multivariate regressions

			1970		2012	
		Sign	Coefficient	Partial R^2	Coefficient	Partial R^2
Sensory	Color discrimination	-	-0.084 (0.095)	0.002	-0.298*** (0.102)	0.019
	Color vision	-	-0.016 (0.112)	0.000	0.015 (0.103)	0.000
	Near Acuity	-	0.016 (0.088)	0.000	-0.075 (0.070)	0.003
	Far Acuity	+	0.290*** (0.101)	0.019	0.140* (0.080)	0.007
	Hearing	-	0.091 (0.138)	0.001	-0.003 (0.110)	0.000
	Noise	+	0.316*** (0.103)	0.021	0.367*** (0.081)	0.045
	Tasting-smelling	-	-0.135** (0.064)	0.010	-0.004 (0.050)	0.000
	Feeling	-	-0.306*** (0.081)	0.031	-0.319*** (0.066)	0.051
Motor	Fingering	-	0.013 (0.099)	0.000	0.109 (0.080)	0.004
	Finger Dexterity	-	-0.316** (0.128)	0.014	-0.184* (0.101)	0.008
	Handling	-	-0.183** (0.090)	0.009	-0.092 (0.070)	0.004
	Manual dexterity	?	0.033 (0.123)	0.000	0.185 (0.126)	0.005
	Motor Co-ordination	-	0.024 (0.108)	0.000	-0.078 (0.096)	0.002
	Eye-Hand-Foot	+	-0.221** (0.088)	0.014	-0.144* (0.077)	0.008
	Clerical Perception	-	-0.196* (0.114)	0.007	-0.141 (0.107)	0.004
Spatial	Spatial skills	+	0.586*** (0.107)	0.065	0.296*** (0.100)	0.020
	Depth perception	+	0.306** (0.123)	0.014	0.413*** (0.099)	0.039
Other Attributes	Physical strength	+	0.466*** (0.115)	0.036	0.481*** (0.108)	0.043
	GED – language	-	-0.085 (0.178)	0.001	-0.243 (0.174)	0.004
	GED – math	+	0.484*** (0.148)	0.024	0.552*** (0.137)	0.036

	Temperament – people	-	-0.057 (0.143)	0.000	-0.114 (0.112)	0.002
	Interest - things	+	0.458*** (0.087)	0.060	0.239*** (0.068)	0.027
	Occupational prestige	+	0.184* (0.109)	0.007	0.132 (0.087)	0.005
	Mortality risk	+	0.118* (0.064)	0.008	0.110** (0.050)	0.011
	Competition	+	0.217*** (0.067)	0.023	0.285*** (0.053)	0.061
	Time pressure	+	0.089 (0.070)	0.004	0.056 (0.054)	0.003
	Structured/. unstructured work	+	0.033 (0.073)	0.001	-0.079 (0.057)	0.004
	Freedom to make decisions	+	0.209*** (0.074)	0.018	0.142** (0.058)	0.014
R^2			0.630		0.720	

Notes: Authors' calculations from 1970 census and 2012 American Community Survey. The estimates for each year are from a regression of the log odds ratio of male to female employment at the occupational level on the indicated measures of occupational skills or aptitudes in the indicated year. ***, ** and * indicate statistical significance at the 10, 5, and 1 percent levels respectively.

Table 5: Predicted Duncan indices negating occupational selection on occupational skills, aptitudes and attributes; univariate results

	1970		2012	
	Duncan	% Δ from Actual	Duncan	% Δ from Actual
Actual	0.644		0.508	
Sensory				
Color discrimination	0.646	0.3	0.502	-1.2
Color vision	0.648	0.6	0.500	-1.6
Near Acuity	0.636	-1.2	0.489	-3.7
Far Acuity	0.636	-1.2	0.498	-2.0
Hearing	0.625	-3.0	0.473	-6.9
Noise	0.619	-3.9	0.445	-12.4
Tasting-smelling	0.643	-0.2	0.510	0.4
Feeling	0.641	-0.5	0.504	-0.8
Motor				
Fingering	0.610	-5.3	0.494	-2.8
Finger Dexterity	0.633	-1.7	0.505	-0.6
Handling	0.644	0.0	0.509	0.2
Manual dexterity	0.648	0.6	0.518	2.0
Motor Co-ordination	0.651	1.1	0.519	2.2
Eye-Hand-Foot	0.627	-2.6	0.470	-7.5
Clerical Perception	0.620	-3.7	0.454	-10.6
Spatial				
Spatial skills	0.580	-9.9	0.475	-6.5
Depth perception	0.577	-10.4	0.426	-16.1
Other Attributes				
Physical strength	0.607	-5.7	0.476	-6.3
GED - language	0.645	0.2	0.507	-0.2
GED - math	0.635	-1.4	0.509	0.2
Temperament – people	0.628	-2.5	0.481	-5.3
Interest - things	0.623	-3.3	0.495	-2.6
Occupational prestige	0.640	-0.6	0.511	0.6
Mortality rate	0.627	-2.6	0.487	-4.1
Competition	0.612	-5.0	0.497	-2.2
Time pressure	0.629	-2.3	0.490	-3.5
Structured/unstructured work	0.643	-0.2	0.508	0.0
Freedom to make decisions	0.633	-1.7	0.507	-0.2

Notes: Authors' calculations from 1970 census and 2012 American Community Survey. The predicted Duncan indices are constructed as per equation (3) in the text based on the estimates in Table 3. All predicted indices are statistically significantly different from the actual Duncan index in the indicated year at the 1 percent level.

Table 6: Predicted Duncan indices negating occupational selection on occupational skills, aptitudes and attributes; multivariate results

	1970		2012	
	Duncan	% Δ from Actual	Duncan	% Δ from Actual
Actual	0.644		0.508	
Sensory	0.617	-4.2	0.472	-7.1
Motor	0.611	-5.1	0.491	-3.3
Spatial	0.574	-10.9	0.455	-10.4
Combined: sensory, motor and spatial	0.510	-20.8	0.393	-22.6
Physical strength	0.622	-3.4	0.476	-6.3
Cognitive	0.632	-1.9	0.508	0
People/things	0.627	-2.6	0.486	-4.3
Occupational risk	0.623	-3.3	0.498	-2.0
Flexibility	0.627	-2.6	0.502	-1.2
Combined – Other Attributes	0.551	-14.4	0.415	-18.3
All	0.420	-34.8	0.299	-41.1

Notes: Authors' calculations from 1970 census and 2012 American Community Survey. "Cognitive includes GED—language and GED—math. "People/Things" includes temperament—people and interest—things. "Occupational risk" includes occupational prestige, mortality risk and competition. "Flexibility" includes time pressure, structured/unstructured work and freedom to make decisions. The predicted Duncan indices are constructed as per equation (3) in the text based on the estimates in Table 4. All predicted indices are statistically significantly different from the actual Duncan index in the indicated year at the 1 percent level.

Table 7: Gender earnings gap decompositions, 2012 and 1970, negating occupational selection on occupational skills, aptitudes and attributes

	Wage differential: total	Wage differential: across occupations	Wage differential: within occupation	% across-occupation
2012				
Actual (all occupations)	$13,942	$4,511	$9,431	32.4
Actual (468 occupations)	$13,942	$4,529	$9,413	32.5
Controlling for:				
Sensory	$14,646	$5,398	$9,249	36.9
Motor	$14,489	$5,184	$9,305	35.8
Spatial	$13,733	$4,515	$9,218	32.8
Combined: sensory, motor, spatial	$15,325	$6,453	$8,871	42.1
Physical strength	$17,193	$8,537	$8,656	49.7
Cognitive	$11,143	$1,245	$9,899	11.1
People/things	$15,911	$6,947	$8,963	43.7
Occupational risk	$9,796	-$501	$10,296	-5.1
Flexibility	$13,546	$4,039	$9,507	29.8
Combined: Other Attributes	$11,763	$1,915	$9,848	16.3
All	$13,270	$4,001	$9,269	30.1
1970				
Actual (all occupations)	$20,704	$4,352	$16,351	21.0
Actual (468 occupations)	$20,608	$4,297	$16,311	20.9
Controlling for:				
Sensory	$20,214	$3,732	$16,482	18.4
Motor	$20,324	$3,805	$16,520	18.7
Spatial	$20,167	$3,983	$16,184	19.7
Combined: sensory, motor, spatial	$19,704	$3,296	$16,408	16.7
Physical strength	$21,575	$5,905	$15,670	27.3
Cognitive	$19,599	$2,820	$16,780	14.3
People/things	$21,474	$5,618	$15,856	26.2
Occupational risk	$19,667	$2,888	$16,779	14.7
Flexibility	$20,080	$3,485	$16,595	17.4
Combined: Other attributes	$20,475	$4,459	$16,015	21.8
All	$19,169	$3,298	$15,871	17.2

Notes: Authors' calculations from the 1970 census and 2012 American Community Survey. 2002 dollars. The decompositions of the gender earnings gap are based on equation (4) in the text. "Cognitive includes GED—language and GED—math. "People/Things" includes temperament—people and interest—things. "Occupational risk" includes occupational prestige, mortality risk and competition. "Flexibility" includes time pressure, structured/unstructured work and freedom to make decisions.