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ABSTRACT

Parental Skills, Assortative Mating, and the Incidence of Autism Spectrum Disorder[1]

We use rich administrative data from Denmark to assess medical theories that autism spectrum disorder (ASD) is a heritable condition transmitted through underlying parental skills. Positing that occupational choices reflect skills, we create two separate occupation-based skill measures and find that these measures are associated with ASD incidence among children, especially through the father's side. We also assess the empirical relevance of assortative mating based on skill, concluding that intertemporal changes in assortative mating explain little of the increase in ASD diagnoses in recent decades.

JEL Classification: I1, J1
Keywords: parental skills, autism

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I. Introduction

The U.S. Centers for Disease Control (CDC) currently estimates that 18.5 per thousand 8-year-olds (1 in 54) residing in the U.S. meet the criteria for diagnosis of Autism Spectrum Disorder (ASD).[2] This prevalence has grown markedly over time; the analogous prevalence in the U.S. was only 6.7 per thousand in 2000 (Maenner et al., 2020), and numerous studies suggest similar trends throughout the developed world.[3] Individuals with ASD have "persistent deficits in social communication and social interaction across multiple contexts" and demonstrate "restricted, repetitive patterns of behavior, interests, or activities," all of which lead to impairment in "social, occupational, or other important areas of current functioning" that cannot be explained by other intellectual or global developmental delays (American Psychiatric Association, 2013). ASD is associated with relatively low educational attainment, poor labor market outcomes, and difficulty with independent living in adulthood.[4]

Researchers have linked diagnoses of ASD to a variety of environmental, economic, social, and especially genetic factors. Recent research (e.g., Satterstrom et al., 2020) has identified specific genes associated with ASD, and various other observed dimensions of the heritability of ASD have been documented. For example, Bai et al. (2020) study a sample of children whose parents do not have ASD, finding that the children diagnosed with ASD are disproportionately likely to have aunts or uncles with ASD. Similarly, monozygotic twins are much more likely to both have ASD than are dizygotic twins (Nordenbaek et al, 2014). Children with ASD (and without other developmental disorders) have fathers with higher IQ scores than

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[2] https://www.cdc.gov/ncbddd/autism/addm-community-report/index.html
[3] Hansen et al. (2015) and Parner et al. (2008) show that rates of diagnosed ASD grew sharply in Denmark, and a comparative prevalence study using all children born in Denmark, Finland, Sweden and Western Australia between 1990 and 2007 shows an increase in prevalence of ASD in all four countries (Atladottir et al., 2015). A recent study using nationwide health registries in Denmark, Iceland, France, and Finland for 2015 reports that ASD prevalence among children aged 7-9 ranged from 0.48% in South-East France to 3.13% in Iceland (Delobel-Ayoub et al., 2020). Poovathinal et al. (2018) focus on the global prevalence of autism (the most severe disorder in the ASD spectrum) by examining sixty-six reports on the epidemiology of autism published during 1966-2017, concluding that autism prevalence has increased worldwide in recent years.
[4] See, e.g., https://www.cdc.gov/ncbddd/autism/autism-spectrum-disorder-in-teenagers-adults.html.

other children, largely due to differences in scores on the technical comprehension section of the IQ test (Gardner et al., 2019). Not all evidence points to a clear role for inherited traits, however; for example, both socioeconomic status (Daniels and Mitchell, 2014) and parental age at birth (King et al., 2009) are positively associated with ASD incidence. While it is clear that at least part of the growth in prevalence over time reflects increased diagnosis net of underlying incidence due to changing diagnostic criteria, improved detection (King and Bearman, 2009), and better information exchange through social networking (Fountain et al., 2011), the rise in ASD rates is not well understood.

Because ASD diagnoses hinge on deficits in social communication and social interaction, coupled with behaviors that involve repetition and inflexibility, researchers have examined whether parents of children with ASD exhibit characteristics associated with some of these same traits (see, e.g., Losh et al., 2017, and Baron-Cohen and Hammer, 1997). Moreover, because social communication and an affinity for order and repetition are characteristics that define dimensions of the skills used in specific occupations, researchers have also examined the relationships between parental occupations and ASD diagnoses in children.[5] Baron-Cohen et al. (1997) find that maternal and paternal grandfathers of autistic children are disproportionately likely to be engineers. Windham et al. (2009) estimate the impact of parental occupation and assortative mating on ASD prevalence, concluding that ASD prevalence is higher among children whose mothers' occupations are "high-tech" relative to other professional occupations. In contrast, Dickerson et al. (2014) find that fathers who work in healthcare or finance occupations are more likely to have children diagnosed with ASD than are fathers in other

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[5] We use the terms "skills" and "traits" interchangeably, taking no stand on whether they are immutable characteristics of individuals.

occupations, but they find no analogous relationships for mothers. All of these studies use either small sample sizes, non-representative samples, or both.[6]

Motivated in part by these small-scale studies of ASD, and by larger-scale evidence from economics that various dimensions of skill are embodied in occupational choices (Autor et al., 2003; Deming, 2017), we use large-scale registry data from Denmark on occupational choices to estimate the links between paternal and maternal skills and diagnoses of ASD in a large population of children. We take two different but complementary approaches to mapping observed occupations into underlying skills, both of which are derived from the Occupational Information Network (O*NET) survey of United States occupations, where we concord U.S.-based occupation classifications to those in Denmark.

Our first approach is derived from a factor analysis we perform on the occupation-specific measures of the importance of a set of "skills and abilities" as defined for U.S. occupations. We particularly focus on those skills highlighted in the context of "systemizing" and "empathizing" traits, as described by Baron-Cohen (2006) and Baron-Cohen and Wheelwright (2004). Individuals with systemizing personalities tend to be attracted to situations involving clear rules and laws, while those with empathizing personalities are skilled at interpreting and understanding the feelings of others. The second approach uses four main measures of task-intensity in the O*NET identified in Deming's (2017) study of the role of cognitive, non-cognitive, and social skills in the labor market.

We begin our empirical analysis by using linear models to estimate the probability that a child is diagnosed with ASD as a function of the occupational choice of the parents, measured by the first three factors of our factor analysis (which account for roughly three-fourths of the underlying variation in the factor model). Examining the correlation structure of the factors with

[6] For example, Windham et al. (2009) study 248 children with ASD matched to 659 case controls, all drawn from the San Francisco Bay Area. Dickerson et al. (2014) use a sample of 211 children diagnosed with ASD and 78 controls from the Houston area.

other key observable characteristics of the data and of occupations, we argue that the first factor captures professional skills of parents, which are highly correlated with measures such as family income. The second and third factors are more specialized. We argue that the second factor captures systems and ordering skills, and roughly accords with the notion of “systemizing” traits. The third factor, on the other hand, captures communication skills and is related to “empathizing” traits. We then use the same empirical approach to examine the link between ASD diagnoses in children and Deming’s (2017) four main measures of occupational task intensity (“routineness”, “non-routineness”, “social skills”, and “service skills”).

Because parental skills are not exogenously assigned, we are wary of interpreting our estimates as capturing causal effects on ASD diagnoses. Nonetheless, we argue that establishing whether such relationships exist, even if correlational in nature, provides insight into the validity of various approaches to conceptualizing parental traits and ASD diagnoses. Our context allows us to address many potential observable and unobserved confounders that are absent in other data sources with sufficient observations to detect effects on ASD. Further, socio-economic disparities in access to diagnoses are modest in Denmark due to a relatively flat income distribution, the availability of universal healthcare, and the availability of disability benefits, thereby reducing the likelihood that such disparities explain the associations that we find.

Our analyses produce four substantive findings. First, we find that our measure of professional skills is linked to lower rates of ASD diagnosis in children. The magnitude of these estimates are sensitive to conditioning on income, so this may be a function of socioeconomic status rather than of underlying skill. Our measures of skill that are linked to communication on the one hand, and systems and ordering on the other, are also associated with ASD in children, but almost exclusively through the paternal side. In our preferred estimate, we find that a one standard deviation increase in the paternal factor linked to systems and ordering is associated with a 0.041 percentage-point increase in the incidence of ASD (2.4 percent of the baseline incidence of 1.71 percent). A one standard deviation increase in the paternal communication skill is associated with a decrease in ASD incidence of 0.063 percentage points (3.7 percent of baseline). Analogous estimates based on those maternal factors are much smaller, typically statistically insignificant, and sometimes of opposite sign than those from fathers.

Second, we find strong associations between Deming's (2017) measures of social skills and ASD diagnoses. Again, only paternal characteristics appear to play a strong role. A one standard deviation increase in paternal social skills is associated with a 0.130 to 0.166 percentage-point (7.6 percent to 9.7 percent of baseline) decrease in the probability of an ASD diagnosis, depending on specification. Similarly, a one standard deviation increase in paternal "routineness" is associated with a 0.103 to 0.120 percentage-point (6.0 percent to 7.0 percent of baseline) increase in ASD diagnoses.

Third, we use our framework to test the theory that ASD is a manifestation of an "extremely systemizing brain", which Baron-Cohen describes as lying in the far right tail of the distribution of systemizing traits in combination with lying in the far left tail of the distribution of empathizing traits. We find mixed evidence for this theory, using our factor measures of communications and systems / ordering as proxies for systemizing and empathizing traits, respectively. The estimates imply that, relative to having parents who both have "balanced" brain types (with roughly equivalent levels of systemizing and empathizing), a child with two extremely systemizing parents has a 0.59 to 0.91 percentage-point higher likelihood of ASD diagnosis. These estimates are strikingly large relative to the baseline incidence of 1.71 percent, and extreme systemizing is similarly important on both the paternal and maternal side. However, in contrast to the predictions of the Baron-Cohen model, we also find large *positive* associations between ASD and extreme empathizing. While these latter findings are sensitive to modeling choice, they suggest that ASD may be a characteristic of extreme parental traits along multiple dimensions.

Finally, we assess the potential role that assortative mating on parental skills has played in recent increases in ASD diagnosis rates. Although we find strong cross-sectional evidence of assortative mating based on the occupation-based skills that we measure, our baseline models imply that such assortative mating has only small (and statistically insignificant) impacts on ASD diagnoses. Moreover, we show that the extent of assortative mating on the skills we consider remained remarkably constant from the 1995 to 2010 birth cohorts while ASD incidence more than doubled, from 0.6 to 1.3 percent. We conclude that the intertemporal patterns of assortative mating – at least based on the occupation-based skills that we measure – likely do not explain a meaningful portion of the dramatic increase in ASD diagnoses in recent decades.

II. Data and Descriptive Statistics

Our primary data are from the Psychiatric Central Research Register (PCRR). Initiated in 1970, PCRR is an electronic record of patients treated at psychiatric departments in Denmark.[7] The register includes clinical information typically provided by discharge abstracts: primary diagnosis, admission and discharge date of inpatient visits, start and end date of outpatient treatments (including emergency room visits), and mode of admission (acute or planned). Since 1994, diagnoses are based on the *International Classification of Diseases*, Tenth Revision (ICD-10). Our main outcome variable is an indicator for having ASD, as determined by ICD-10 codes of F84.0 (childhood autism), F84.1 (atypical autism), F84.5 (Asperger syndrome), F84.8 (other pervasive development disorders), and F84.9 (pervasive developmental disorder, unspecified).[8]

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[7] See Mors et al. (2011) for a detailed description of the PCRR.
[8] ASD is defined as a single diagnosis related to multiple conditions in the Diagnostic and Statistical Manual of Mental Disorders Version 5 (DSM-5) published in 2013. All of the subtypes we classify as ASD fall under the criteria described in the DSM-5 for ASD (https://www.autismspeaks.org/autism-diagnosis-criteria-dsm-5). In our final sample, 32% of children who we identify as having ASD have the ICD-10 diagnosis code for autism, 23% are diagnosed with Asperger's disorder, 12% with atypical autism (which by definition is typically accompanied by intellectual disabilities), and the remaining with other pervasive developmental disorders.

Lauritsen et al. (2010) assessed the ASD diagnosis measures in the PCRR and found that they exhibited high levels of construct validity. The PCRR registry is linked to a series of other registers that provide us with family linkages between children and their parents and grandparents, birth records, education levels, employment, and basic demographics (from population registers).

We focus on three measures of ASD incidence. Our primary outcome is whether a child is diagnosed with ASD at any age. We also measure diagnosis with ASD by age 8, restricting to birth cohorts in which we observe the child through age 8 (1995-2006), and autism diagnosis based solely on the F84.0 ICD-10 code ("childhood autism").[9] Appendix A describes how ASD is diagnosed and treated in Denmark.

Our analysis sample includes all children born in Denmark between 1995 and 2010.[10] We restrict our first cohort to 1995 to ensure that reporting and diagnosis of ASD remains stable during our study period.[11] In total, 1,069,647 children are born during this period. Using unique individual identifiers (scrambled social security numbers provided by Statistics Denmark), we link these children to their biological parents and grandparents. We identify parents using the Danish Medical Birth Register (MBR), which includes information on all births in Denmark since 1973.[12] Maternal identifiers are available for all children. If the mother is married, her husband is assumed to be the father, and his identifier is recorded in the data. If the mother is unmarried, then the identifier of the father is available if the father has claimed the child. In our

[9] Note that because we only know the year of birth, we define age as the calendar year of diagnosis minus the calendar year the child is born. For example, if we define a child as being 8 years old, his/her true age is actually between 7 (e.g. born on December 31, 1995 and diagnosed on January 1, 2003) and 9 (e.g. born on January 1, 1995 and diagnosed on December 31, 2003) years old.
[10] We have assessed the robustness of our results to using only first-born children in order to eliminate a potential sample selection bias from endogenous fertility responses to having a child with ASD. The results (available upon request) are very similar to the results from the full sample.
[11] As noted above, diagnosis of ASD is based on ICD-10 starting in 1994. In addition, PCRR was expanded in 1995 to include outpatient and emergency room contacts (previously only inpatient care was included). Previous research found that these two reporting changes jointly explain 60% of the rise in ASD diagnosis among children born in Denmark between 1980 and 1991 (Hansen et al., 2015).
[12] For more information, see Knudsen and Olsen (1998).

sample, 98.8% of children are matched to their fathers. Grandparents are defined using the Population Register as the legal parents of the child's parents at the time of birth. We are able to match 89.9% of the children to their maternal grandfather and 88.4% to their paternal grandfather. Overall, before restricting our samples to those children for whom we have non-missing information for the relevant variables for fathers, mothers, and grandparents, our sample includes 1,023,494 children matched to both parents and 860,447 matched to both sets of grandparents.

II.1 Creating Measures of Skills as Embodied in Occupations

We construct our main independent variables of interest by mapping parents' occupations into measures of skills, based on two different taxonomies that are derived from the Occupational Information Network (O*NET) survey of US occupations. The O*NET is a US Department of Labor-sponsored project that provides information on each of the almost 1,000 unique occupations in the US Bureau of Labor Statistics' Standard Occupational Classification (SOC).

We first leverage information from the O*NET's ratings for a set of unique knowledge categories, skills and abilities (KSAs) for each occupation, which O*NET develops using information from occupation analysts, experts, and workers themselves. In particular, we use the O*NET's 35 unique "skills" and 52 "abilities" (the "SA" part of "KSA") to develop measures of the intensity of different traits across occupations.[13] The O*NET assigns a score between one and five for the importance of each SA to an occupation, with five being the highest level of importance. As an example, the occupation "Mechanical Engineer" has an O*NET (version 22.0) importance score of 2.88 for the skill of "*social perceptiveness*" and an importance score

[13] We exclude the "knowledge" category from the KSAs in our analysis, as the knowledge measures tend to capture information learned in school rather than underlying characteristics. We do not consider the difference between the terms "skills" and "abilities" as defined by O*NET to be meaningful, and we refer to our derived measures from both as "skills" or "traits".

of 4.00 for the ability "*information ordering*". The occupation "Child, Family, and School Social Workers", in contrast, has importance scores of 4.12 and 3.62 for *social perceptiveness* and *information ordering*, respectively.[14]

The SAs do not perfectly overlap with characteristics associated with the diagnosis of ASD, but many of them are sufficiently evocative to infer that there may be links. For example, *social perceptiveness* may be related to what is described in ASD diagnoses as "social communication or social interaction" while *information ordering* may well be related to "restricted patterns of behavior".

In order to measure the variation of skills across occupations in the O*NET, we construct a matrix of importance scores of the SAs in the O*NET across all occupations and perform a factor analysis on it. This procedure converts the large matrix of importance scores of SAs across occupations into a small number of factors that capture much of the variation in the matrix.

The first three factors of the factor analysis account for 76 percent of the variation in importance scores, and we therefore limit our focus to them. It is instructive to examine the factor loadings across SAs in order to conceptualize the different dimensions of skill that each of the factors captures. Table 1 lists the SAs with the top 10 and bottom 5 factor loadings corresponding to each factor. For Factor 1, the top 10 factor loadings pertain to written, reading, and oral expression or comprehension, along with "social perceptiveness," "speaking", "inductive reasoning", and "critical thinking". This factor, however, negatively loads on physical skills such as "manual dexterity". In contrast, the top 10 SAs for Factor 2 include "reaction time", "troubleshooting", "operation monitoring" and "systems analysis". Of the top 10 factor loadings for Factor 3, three overlap with the top 10 for Factor 1 ("social

[14] For information on importance scores and how they have been used in the O*NET, see National Research Council (2010).

perceptiveness", "oral expression", and "oral comprehension"), and seven are related to speech or interactions with others. Notably, "mathematical reasoning" and "troubleshooting" have the largest negative factor loadings of any SAs for Factor 3, but have large positive loadings on Factor 2 (Appendix Table A1 shows all standardized factor loadings for these three factors; the factor loading of "mathematical reasoning" is 0.030 for Factor 2).

To further highlight the differences across the three factors, in Figure 1 we present three two-way plots that show examples of the first three factor scores across a selection of occupations.[15] The top plot graphs Factor 1 and Factor 2 for these occupations. Jobs with high Factor 1 scores but low Factor 2 scores (in the upper left-hand area of the plot) include lawyers, economists, and religious professionals. Police officers have a roughly average Factor 1 score, but a high Factor 2 score. Plumbers and pipe fitters, along with carpenters and joiners, have low Factor 1 scores and slightly below average Factor 2 scores.

The middle plot graphs Factor 1 against Factor 3. Note that for the occupations shown in the plot, there is significantly more variation in Factor 3 than there is in the other factors. Computer programmers, economists, chemists, and mechanical engineers have high levels of Factor 1 but low levels of Factor 3, whereas religious professionals and lawyers have high levels of both. Child-care workers and police officers have the highest levels of Factor 3, reflecting the importance of communication skills in these professions.

The final plot graphs Factor 2 against Factor 3. Tailors, dressmakers, and hatters have the lowest Factor 2 score, along with below-average Factor 3 scores. Note that economists also fall in the lower left quadrant, with below average scores in both Factor 2 and Factor 3.

[15] In order to merge our indices to the Danish registry data, we use a crosswalk provided by the Institute for Structural Research at the University of Warsaw. These data convert occupation codes from Standard Occupation Codes for 2000 (SOC-00) used in the O*NET database to International Standard Classification of Occupations for 1988 (ISCO-88), which are the occupation codes used in Danish registries. Unfortunately, the SOC-00 codes do not perfectly align with ISCO-88. In particular, many SOC-00 codes match to multiple ISCO-88 codes and vice-versa. In order to convert the U.S. occupation index to Danish occupations, we average each of our indices over all SOC-00 codes that match to each four-digit ISCO-88 code.

We draw three general conclusions from these descriptive facts about the factors, the factor loadings, and the differences across occupations. First, Factor 1 appears to capture a set of general skills often acquired through formal education, and relatedly, the occupations with high Factor 1 scores generally require a college education, whereas the opposite is true for occupations with low Factor 1 scores. Because of these features, we refer to Factor 1 as "Professional Skills Factor" (PSF) hereafter. Second, Factor 2 captures a set of skills that do not reflect the types of general skills one associates with formal education; instead, this factor is related to occupations in which systems and / or rapid problem-solving skills are important, such as air traffic controllers, chemists, computer assistants, and medical professionals. We refer to this factor as the "Systems and Ordering Skills Factor" (SOF). Third, while Factor 3 overlaps with PSF, it is especially related to skills that involve interacting with people; for example, the lowest score shown in Figure 1 is for computer programmers, while the highest scores include child-care workers and police officers. We refer to this factor as the "Communication Skills Factor" (CSF).

As an alternative way of measuring how occupational choices reflect parental skills, we use Deming's (2017) four main measures of task intensity, which are also derived from the O*NET and are based on Autor et al. (2003). Deming's goal was primarily to examine the changing importance of social skills in labor market outcomes in the United States, but to do so he categorizes the task intensity embedded in occupations into four (main) composite categories: *social skills, routineness, non-routine analytical skills*, and *service.*[16] Some, but not all, of the components of these categories are derived from the O*NET's SA's.

Deming (2017) constructs *social skills* task intensity as the average of four variables in the skills component of the O*NET database: *social perceptiveness* ("being aware of others'

[16] Deming's (2017) Online Appendix describes 10 composite categories of occupational task content, but he notes that the four categories we use are his preferred measures.

reactions and understanding why they react the way they do"), *coordination* ("adjusting actions in relation to others' actions"), *persuasion* ("persuading others to approach things differently"), and *negotiation* ("bringing others together and trying to reconcile differences"). *Service* is the average of two variables in a different component of the O*NET (work activities): *assisting and caring for others* ("providing assistance or personal care to others") and *service orientation* ("actively looking for ways to help people"). Both *social skills* and *service* are similar to aspects of our CSF measure, which loads heavily on the SA's of *persuasion*, *negotiation*, *service orientation*, and especially, as mentioned above, *social perceptiveness*.

Routineness is the average of two measures (*degree of automation* and *importance of repeating some tasks*) that are not part of O*NET's SAs, but they may well be important dimensions of occupations that are relevant to ASD because they at least partly suggest occupations where repetition and order are important. *Degree of automation* is defined as "the level of automation of this job" and *importance of repeating some tasks* measures "the importance of repeating the same physical activity (e.g. key entry) or mental activities (e.g., checking entries in a ledger) over and over, without stopping, to perform a job." *Non-routine analytical* is a composite measure constructed as the average of three variables: *mathematical reasoning, mathematical knowledge,* and *mathematics skill.* Note that *mathematical reasoning* is one of the skills in the SA's, and as mentioned above, has a high factor loading for PSF and an especially low (negative) one for CSF.

In practice, Deming's (2017) four measures (which we update using the more recent waves of O*NET), capture some similar but not identical skills to those in our three factors.[17] Moreover, while Deming refers to his measures as capturing "task intensity", the fact that they

[17] Deming (2017) uses data from the 1998 release of the O*NET to obtain measures of occupational skills, abilities, and task content. We supplement these measures with the June 2009 (O*NET 14.0) and August 2017 (O*NET 22.0) releases, which include occupations not found in earlier releases. See https://www.onetcenter.org/db_releases.html for more details about O*NET releases.

are at least partly derived from the SA components of the O*NET imply that the differences between "tasks" and "skills" are minor, at least for our purposes.

Figure 2 shows raw scores on Deming's measures for the same occupations as in Figure 1, revealing some broadly similar patterns. The top panel shows, for example, that computer programmers have high *routineness* and low *social skills*, while lawyers exhibit the opposite patterns. The bottom panel shows that computer programmers have high *non-routine analytical skills* and low *service skills*, while lawyers have relatively moderate levels of both.

In Table 2, we present a full matrix of correlations of the measures of skills we use – the three factors and the four Deming measures. By construction, the factors are essentially uncorrelated with each other. In general, PSF is more highly correlated with each of Deming's measures than the other factors; it is strongly positively correlated with *social skills* (with a correlation coefficient of 0.87), *non-routine analytical skills* (0.64), and *service skills* (0.59), and negatively correlated with *routineness* (-0.20). SOF is most correlated with *non-routine analytical* (0.43) and somewhat correlated with *social skills* (0.28), but effectively uncorrelated with *routineness* and *service skills*. The correlations between Deming's measures and CSF are more varied. CSF is negatively correlated with both *routineness* and *non-routine analytical* (-0.30 and -0.40, respectively), but positively correlated with *social skills* (0.28) and *service skills* (0.50). Taken together, the correlations imply that Deming's measures and the factor measures bear important relationships to one another, but they capture different aspects of occupations.

One unique characteristic of the factor-based skill measures is that they appear to relate closely to the concepts of "systemizing" and "empathizing" proposed in Baron-Cohen (2002), Baron-Cohen and Wheelright (2004), and Baron-Cohen (2006) as being potential drivers of ASD. These authors hypothesize that ASD is an extreme realization of systemizing and empathizing traits, which may be heritable.[18] Additionally, Baron-Cohen speculates that increased assortative mating on these (and potentially other) traits may be partly responsible for the dramatic increases in ASD since the early 1990's. We return to these hypotheses in Section V below.

Because some of the parents in the Danish registry data change occupations over time – and some have periods of non-employment – we create occupational skill measures as the average of each of the skill measures over the occupations listed in each year in which the parent is between 25 and 34 years old.[19] This helps maximize the number of individuals included in our estimation samples while ensuring that the skill measures are typically based on multiple years of data. Finally, we standardize each measure within each person's own gender group (that is, within men for fathers and within women for mothers) to make them interpretable and more easily comparable across measures. Hence, all our results can be interpreted as the relationship between ASD in a child and the parent's place in their gender-specific underlying distributions.

II.2 Other Features of the Data Used in Estimation

In addition to the indices of parental skills described above, in our empirical specifications we include characteristics known to be associated with the likelihood of ASD in children. In particular, we control for the gender of the child, parental age, marital status of parents at birth, and indicators for parental field of study.[20] We also control for indicators for the parish of the child's birth registration to capture time-invariant geographic differences in the

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[18] This hypothesis, known as the Empathizing-Systemizing Theory of ASD, was originally described as the "Extreme Male Brain" theory of Autism by Baron-Cohen (2002).

[19] We drop parents from the sample if we never observe an occupation for them within the relevant age range. This primarily affects mothers. Further, since we only have access to the year of birth, we define a person's age as the age had they been born on January 1 of their birth year.

[20] We obtain demographic characteristics from the Population Register, which includes all individuals with permanent residence in Denmark on January 1 of each year. It contains a snapshot of demographic data such as marital status, gender, date of birth, place of birth, place of residence, and citizenship. The data are updated annually. More details on this register are available in Pedersen (2011).

propensity to diagnose ASD.[21] Finally, we control for the income history of parents to account for socio-economic status and broad skill levels of the family. Specifically, we include (1) gross personal income from all sources including transfers and (2) total taxable salary (which excludes transfers). For each of these measures we include the values for each year the parent is between ages 25 and 34. If there is no reported income then we set income to zero and set a missing indicator for that parent-year equal to one. Once we restrict the sample to children who have full data for both themselves and their parents, we include 738,126 children for our main analysis (recall from above that we are able to match 1,023,494 children to their parents).

Table 3 provides summary statistics for our main analysis sample. Column (1) includes the full analysis sample, column (2) includes only children diagnosed with ASD at any age in our sample, and column (3) includes only children who are not diagnosed with ASD. Of the children with ASD, only roughly 22.7 percent are female, which consistent with information reported elsewhere that ASD is nearly four times more common in boys than in girls.[22] Parents of children diagnosed with ASD are slightly younger than parents of children without ASD, and they have lower education levels. King et al. (2009) note an increase in the prevalence of ASD in children when parental age at birth is 40 or higher. In our sample, however, parents are on average much younger than 40: the average age of fathers among children with ASD is 31.6 (compared to 32.3 for children without ASD), and the average age of mothers among children with ASD is 29.6 (compared to 30.3 for children without ASD).

In Panel B of Table 3, we report summary statistics for the three factors from our factor analysis (PSF, SOF, and CSF), and we report standardized Deming (2017) skill measures in Panel C. Note that the means in column (1) of these two panels are not all equal to zero, as we standardize using the *full* population of each gender with work histories observed between ages

[21] The specific birth parish variable we use is "foedreg_kode." Ninety-six percent of births are registered in birth locations we can identify. These locations were originally based on ecclesiastical boundaries but now serve solely to designate administrative regions. Our sample includes 2219 unique birth registration parishes.
[22] See for example, https://www.cdc.gov/ncbddd/autism/data.html.

25 and 34, rather than our restricted sample of the parents of the children in our sample. In general, comparing columns (2) and (3) in Panel B, fathers and mothers of children with ASD appear to work in occupations with lower PSFs, and mothers of children with ASD appear to work in occupations that have lower SOFs and higher CSFs. In Panel C, fathers of children with ASD are disproportionately likely to work in occupations that require high levels of routineness and that do not require social skills. They also tend to be in occupations for which non-analytic skills are relatively unimportant. For mothers, these patterns are similar except that the routineness gap is smaller.[23]

III. Empirical Strategy

In order to measure the relationship between parental skills and diagnoses of ASD, we begin by estimating equations of the form

$$(1)\ ASD_i = \alpha + \beta_1 PSF_{M_i} + \beta_2 SOF_{M_i} + \beta_3 CSF_{M_i} + \gamma_1 PSF_{D_i} + \gamma_2 SOF_{D_i} + \gamma_3 CSF_{D_i} + X_i\lambda + \varepsilon_i$$

where ASD_i is an indicator equal to 1 if child *i* is diagnosed with an Autism Spectrum Disorder and zero otherwise, PSF_{M_i}, SOF_{M_i}, and CSF_{M_i} are measures of the three factors in the mother's occupation choice(s), and PSF_{D_i}, SOF_{D_i}, and CSF_{D_i} are analogous measures for the father. We also estimate variants of specification (1) in which we include all four of Deming's (2017) measures. In all cases, as with the summary statistics we reported in Table 3, we standardize the indices within gender in the full population. The vector X_i includes sets of family and environmental characteristics that represent risk factors for ASD as described above, as well as birth year and parish of birth fixed effects. Standard errors are clustered at the birth cohort by parental education level.

[23] Appendix Table A3 lists the incidence of childhood ASD by the full list of 2-digit ISCO-88 occupational codes, separately for paternal and maternal occupations.

We estimate specification (1) via OLS. One could instead estimate versions of Equation (1) using limited dependent variable models, but this is difficult in our context because we include high-dimensional parish-of-birth fixed effects, generating an incidental parameters problem. Although the relatively low diagnosis rate of ASD could result in negative predicted values in a linear probability model, it will not lead to bias in the estimates of the parameters of Equation (1) (Angrist and Pischke, 2008).

We also estimate extended models where we add to Equation (1) the interaction terms $PSF_{M_i} \times PSF_{D_i}$, $SOF_{M_i} \times SOF_{D_i}$, and $CSF_{M_i} \times CSF_{D_i}$ in order to assess the impact of parental assortative mating based on each of the factors. As noted above, several authors, including Baron-Cohen (2006), Baron-Cohen et al. (1997), Roelfsema et al. (2012), and Windham et al. (2009), have speculated that assortative mating plays a significant role in ASD diagnoses.

A potential obstacle to obtaining interpretable estimates of the impacts of the skills of mothers, as well as the impacts of assortative mating, stems from the possibility that female occupational choice may be distorted due to labor market barriers faced by women, affecting either their choices of occupations or their labor force participation. We address this issue in several ways. First, we use information on any occupation in which a woman works between ages 25 and 34, and we eliminate any periods where she did not participate in the labor market. Second, we standardize our indexes for mothers within the distribution of women only, recognizing that selection into occupations is different for women than for men. Third, we also estimate our regressions substituting occupational information for maternal and paternal grandfathers of the children, in place of the corresponding measurers for their parents, as in Baron-Cohen et al. (1997).

Finally, we consider the possibility that ASD is particularly sensitive to specific extremes in inherent skills of individuals. Building on previous work that characterizes skills along the dimensions of systemizing and empathizing, Baron-Cohen (2002) proposes a classification system involving five distinct brain types: balanced, systemizing, empathizing, extreme systemizing, and extreme empathizing. We explain below how we map these notions of systemizing and empathizing into our skill measures, and we examine whether Baron-Cohen's Empathizing-Systemizing theory of the relationship between extreme systemizing and ASD is observable in our data.

IV. Results

IV.1. Baseline Results

Table 4 presents estimates from linear probability models of equation (1), using the three skill measures derived from our factor analysis. Column (1) presents baseline results in which we include the three factors linearly (and separately) for the father and mother of the child, in addition to controls for the child's sex, parents' age, mother's marital status, child's birth year, parents' educational attainment, and parish fixed effects. Some of these controls are known to be risk factors for ASD diagnoses (Werling and Gerschwind, 2015; Lauritsen et al., 2005). Others reflect socioeconomic proxies that can affect diagnosis rates, such as educational attainment of parents (Daniels and Mandell, 2014). The parish fixed effects control for geographic differences in environmental factors that could affect ASD propensity and geographic variation in the propensity of physicians to diagnose ASD (or the propensity of parents to seek out diagnoses or treatment). The birth year fixed effects control for secular changes in ASD diagnosis rates that reflect either true changes in ASD or rising diagnosis rates for the same underlying conditions.

Estimates of the baseline model in column (1) suggest that higher paternal and maternal PSF are both strongly associated with a lower risk of ASD in children, whereas SOF for either parent has no significant relationship with ASD. The estimates for CSF suggest that paternal CSF is negatively associated with diagnoses of ASD in children, but that the association is positive for maternal CSF.

As mentioned above, PSF appears to capture features of occupations that are related to general skills, and as such may reflect socioeconomic status not fully captured by our education measures. Because of this, in column (2) we report estimates from models in which we include the full set of controls for parental income history from ages 25 through 34. Given that our core interest is assessing the associations of specific dimensions of parental skills and ASD diagnoses in children, we view these as our preferred estimates.

In column (2), the point estimates on both paternal and maternal PSF scores are negative, but they are much smaller than those to column (1). A one standard deviation increase in the PSF score of a mother is associated with a 0.058 percentage-point decline in the probability of ASD diagnosis, which is 3.6 percent of the baseline diagnosis rate of 1.7 percent (we display point estimates multiplied by 100 throughout, in order to represent percentage-point changes in ASD incidence). The coefficients on maternal SOF and maternal CSF are similarly attenuated toward zero relative to column (1) and are not statistically significant at the 5 percent level. This may suggest that maternal skills across occupations are not especially well differentiated from income (or for the socioeconomic factors for which income is a proxy), a sign that perhaps occupation is not a clear signal of underlying skills for women.

In contrast, the coefficients on paternal SOF and paternal CSF are larger (in absolute value) in column (2). The coefficient estimate on the paternal SOF score is 0.042 (0.015), implying that a one standard deviation in father's SOF increases the probability of ASD diagnosis by 2.3 percent of the baseline diagnosis rate. The coefficient on paternal CSF implies that a one standard deviation increase in the CSF score of a father is associated with a 0.062 percentage-point decline in the probability of ASD diagnosis, a 3.6 percent decrease relative to baseline. It is worth noting that the negative association between paternal CSF and ASD diagnoses in children is robust across all of the specifications and sensitivity analyses we report below.

To the extent that CSF captures the dimension of skills related to interacting with people, the negative point estimates for paternal CSF could reflect that children who have received a diagnosis of ASD, and thus have demonstrated challenges with social interactions, are more likely to have fathers who themselves have deficits in skills associated with social interaction. Similarly, to the extent that SOF captures the dimension of skill related to systems and ordering, the results are suggestive that children with ASD, who have restricted or repetitive behaviors, are more likely to have fathers who work in occupations where systems analysis and processing is important.

IV.2. Systemizing, Empathizing, and Assessing the "Extreme Brain" Hypothesis

Thus far, we have not linked our skill measures to specific characteristics that have been hypothesized to be related to ASD. In this section, we focus on one key theory in psychiatry that links specific characteristics of parents to ASD – the Empathizing-Systemizing (E-S) Theory of ASD. In this theory, ASD is the manifestation of what is called an excessively "systemizing" personality (e.g., Baron-Cohen, 2006), often in combination with a deficit in the trait of "empathizing" (Baron-Cohen and Wheelright, 2004).[24] According to the theory, systemizing individuals will tend to be attracted to educational fields and occupations that involve well-defined systems such as engineering, information technology, computer science and natural sciences. Some empirical evidence supports this sorting of "systemizers" into technical occupations. For example, Billington, Baron-Cohen, and Wheelright (2007) show that after accounting for gender, students with high systemizing quotient (SQ) relative to empathizing quotient (EQ) are more likely to major in physical sciences, while those with higher EQ relative to SQ are more likely to major in humanities (we provide more details on SQ and EQ below).

[24] Figure 1 from Wheelright et al. (2006) illustrates that people with ASD are more likely than the general population to show systemizing tendencies, and Figure 2 from Baron-Cohen and Wheelright (2004) illustrates that people with ASD are less likely to be empathizing than the general population.

Baron-Cohen (2006) theorizes based on observational evidence that systemizing is heritable, so that high-SQ parents are more likely to have high-SQ children. Moreover, he argues that assortative mating based on systemizing will lead to an increased prevalence of extremely systemizing offspring, leading to higher ASD rates in children than in the absence of assortative mating.

While we do not have direct measures of systemizing and empathizing in our data, we have explored in detail the relationship between our three skill factors and systemizing diagnostic tests of systemizing and empathizing that have been developed by psychiatrists. These diagnostic tests are two questionnaires intended to measure an individual's EQ and SQ.[25] As detailed in Appendix B, we created a concordance between each of the SAs and the items in the two questionnaires, effectively constructing our own measures of SQ and EQ across occupations. We then examine the relationship between our three skill factors and our constructed measures of SQ and EQ. Given the discussion in Section II.1, it should not be surprising that our measures of SQ and EQ are correlated in expected ways with SOF and CSF. In particular, the correlation between SOF and our SQ is 0.81, and the correlation between CSF and our EQ is 0.52. In contrast, the correlation between SOF and our EQ is 0.15 and between CSF and our SQ is -0.17.[26]

As a part of E-S theory, Baron-Cohen (2002) classifies individuals as falling into one of five brain types, and he hypothesizes that individuals with ASD fall into one of these categories. In this classification, systemizing (empathizing) brains occur when SQ (EQ) is more than one standard deviation greater than EQ (SQ), extreme versions involve differences between SQ and EQ larger than two standard deviations, and "balanced" brains are those in which the difference between SQ and EQ is less than one standard deviation. Baron-Cohen suggests that individuals

[25] These tests are available at https://www.autismresearchcentre.com/arc_tests.
[26] The first factor, PSF, is strongly positively correlated with both of our constructed SQ (correlation of 0.45) and EQ indexes (0.83), providing further support for the idea that PSF captures skills that are more general in nature.

with ASD are much more likely to be extreme systemizers, and given the potential genetic link, one should expect that parents of children with ASD should be more likely to be extreme systemizers, though such a relationship between parents and children could also potentially form through environmental interactions between the child and the parent during development. While we are able to test for the existence of these parent-child links, we are unable to distinguish between heritability and the parents' interactions with the child being proximate causes.

We next use SOF and CSF as proxies of systemizing and empathizing, respectively, to examine Baron-Cohen's typology of the five brain types and the relationship with ASD. We categorize mothers and fathers as having one of five brain types as described above, and we estimate modified versions of Equation (1) where we include dummy variables for each of the brain types for mothers and fathers: extreme empathizing, empathizing, extreme systemizing, systemizing, or balanced (which is the omitted category in our regressions). Table 5 presents the results.[27]

The first two columns of the table report estimates from a model where we include indicators for the brain type for each parent. Column (1a) reports the coefficients for paternal brain type, and column (1b) reports the coefficients for the maternal brain type (both sets of indicators are included in a single estimated model). The results suggest that extreme types matter for ASD. Consistent with Baron-Cohen's theory, extreme systemizing of both mothers and fathers matters, both qualitatively and statistically – the coefficients on extreme paternal and maternal systemizing are 0.376 (0.047) and 0.217 (0.057). In comparison to two parents with balanced brain types, the estimates imply that having two extremely systemizing parents is linked to an increase in ASD incidence of 0.593 (= 0.376 + 0.217) percentage points, which is more than one-third of the baseline incidence of 1.71 percent. In contrast to the theory, though,

[27] Appendix Table A4 lists the incidence of ASD by the most common occupations in each of the five brain types, separately for men and women.

extreme empathizing among parents is also positively related to ASD in children, especially for mothers.

In the next two columns, we add controls for the three factors linearly in the regressions. By including the factors linearly into the model, the specification is identical to that shown in Table 4 but also includes the controls for parental brain type. Additionally, this model provides insight into how extreme typologies relate to ASD once one conditions on the underlying levels of each factor individually, e.g., how much does the difference between the factors matter as opposed to each factor on its own? The point estimates on empathizing of both parents are smaller than in the first two columns and noisy enough to render them insignificant. On the other hand, extreme systemizing of both parents is associated with large increases in ASD in children. Regardless of specification, the evidence is consistent with the idea that ASD is related to extreme parental traits, especially extreme systemizing.

IV.3. Assortative Mating and ASD

We next turn to the role of assortative mating and the rise in ASD. We first examine the extent of assortative mating based on our factors. In Figure 3, we present a series of binned scatterplots that provide evidence of the existence of assortative mating. Each figure shows the relationship between parents' residualized and standardized factor scores, where we have residualized each index by the control variables included in the regressions reported in column (2) of Table 4. We residualize the indices in order to focus on the potential impact of assortative mating on ASD in children conditional on other observable characteristics of parents.[28] We see clear patterns of positive assortative mating across the three (residualized) factors. Specifically, a one standard deviation increase in residualized PSF for mothers is associated with a 0.13 SD

[28] The line in the figure is from the regression of the residualized value of the father's factor on the mother's residualized factor.

increase in residualized PSF for fathers. Similarly, we find estimates of 0.11 for both SOF and CSF. Hence, there is clear assortative mating behavior occurring in the cross section along all three skill dimensions.[29]

We turn next to assessing the potential role on ASD diagnoses of assortative mating based on parental skills. Returning to Table 4, in columns (3) and (4) we report estimates from specifications that are identical to the first two columns of the table but also include, for each factor, interactions between the maternal and paternal factor scores. The estimated coefficients on each of the paternal and maternal factors are essentially unchanged from the first two columns, and the estimates on each of the three interaction terms are small and statistically insignificant. Thus, despite the strong tendency of parents to sort along these dimensions, there does not appear to be a relationship between having two parents with high skills and ASD beyond the individual parental effect (although as we showed above, the linearity assumption may be hiding some relevant tail behavior, a point to which we return below). Perhaps more importantly, in order for assortative mating on skills to play a role in the increased incidence of ASD over time, the extent of assortative mating must also be increasing over time. In order to investigate how the strength of assortative mating evolved during our analysis period, we estimate models of the form:

$$(2) \qquad PSF_{D_i} = \delta_0 + \beta_0 PSF_{M_i} + \sum_{c=1996}^{2007} \{1(BC_i = c) \times [\delta_c + \beta_c PSF_{M_i}]\} + \varepsilon_i,$$

where PSF_{D_i} is the residualized *PSF* measure for the father of child *i*, PSF_{M_i} is similarly defined for the mother, and $1(BC_i = c)$ is an indicator that equals 1 if child *i* is born in birth cohort *c*, and zero otherwise. The estimate of β_0 captures the strength of assortative mating in the 1995

[29] We also investigate whether there is cross-factor assortative mating. Most of the cross-factor estimates using residualized factors are negative but very small relative to the same-factor relationships – the largest in absolute value is -0.03 SD.

birth cohort, while the estimates of β_c capture the strength of assortative mating in subsequent cohorts, relative to 1995. We estimate versions of Equation (2) for CSF and SOF as well.

In Figure 4, we plot the estimates of β_c for all three factors for each birth cohort from 1996 to 2007. For the PSF, the estimate of β_0 is 0.146 (0.005), so that there is strong evidence of assortative mating in 1995, but the key insight is that the trend over the subsequent 12 birth cohorts is decreasing – the strength of assortative mating on the Professional Skills Factor has declined over time. The second and third panels show analogous estimates for SOF and CSF, again showing clear evidence of assortative mating based on these factors: the relevant estimates of β_0 are 0.100 (0.005) and 0.101 (0.005), respectively. In both cases, though, the trends over the birth cohorts are relatively flat, with the 95 percent confidence intervals including zero for nearly all years. Taken together, the patterns shown in Figure 4 suggest that there has been little, if any, change in assortative mating across birth cohorts.

As a complement to the estimates displayed in Figure 4, we also consider a back-of-the-envelope calculation to calculate plausible upper bounds on the role that assortative mating plays in the increase in ASD over time. To do so, we estimate variants of Equation (2) that impose linear trends in assortative mating. The resulting estimates based on SOF imply an annual increase in assortative mating of 0.0013 (0.0003), so that the effect of a one-unit increase in maternal SOF on paternal SOF is 0.0156 (= 0.0013 × 12) larger in the 2007 birth cohort than in the 1995 birth cohort, with a 95% confidence interval of (0.089, 0.0223). We use the upper limit of that confidence interval, 0.0223, as our estimate of the upper bound of the increase in the strength of assortative mating over time. Similarly, the upper limit of the 95 percent confidence interval of our estimated coefficient on "Paternal × Maternal SOF" from column (4) of Table 4 is 0.0216 percentage points (based on a point estimate of -0.006 and a standard error of 0.014). Thus, our upper-bound estimate of the effect of an increase in assortative mating over time on ASD diagnoses is 0.00048 percentage points (= 0.0223 × 0.0216), which is less than 0.1

percent of the observed increase in ASD incidence over this period (from 0.6 to 1.3 percent). We reach similar conclusions for CSF: using calculations analogous to those above, we find that changes in assortative mating based on CSF explain less than 0.1 percent of the increase in ASD incidence between the 1995 and 2007 birth cohorts. Finally, the downward trend in assortative mating based on PSF is inconsistent with the idea that changes in assortative mating on PSF has driven increases in ASD incidence, given that the estimate on the PSF interaction in column (4) of Table 4 is positive.[30]

We acknowledge that our factor scores are measured with error, in that they are not perfect measures of parents' skills, and that phenomenon may be particularly pronounced among women. Such error potentially attenuates the estimates toward zero, and as mentioned above, this may explain why the estimated effects on maternal skills for all three factors declines when we control for income in Table 4. However, even if the resulting error-corrected estimates were two orders of magnitude larger than what we find, assortative mating would still explain less than 10 percent of the increase in ASD incidence between the 1995 and 2007 birth cohorts. While we are hesitant to conclude that assortative mating played no role in the growth in ASD incidence over time, we cannot detect evidence of this role in Denmark over the birth cohorts in our sample.

IV.4 Results Using Deming's Measures of Parental Skills

We next turn the associations between Deming's (2017) four measures of task intensity and ASD diagnoses. In the first four columns of Table 6, we report results where we include each measure one-by-one in models analogous to specification (1) (along with the full set of

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[30] We have also produced variants of Figure 4 that focus on extreme realizations of skills. In particular, we estimated Equation (2) using residualized measures of extreme systemizing and extreme empathizing and then plotted estimates of β_c for these factors for each of the 12 birth cohorts from 1996 to 2007. We found that assortative mating of extreme sympathizers has remained remarkably stable over time, whereas assortative mating of extreme empathizers has slightly decreased. While the latter finding is interesting in its own right, it cannot explain increases in ASD over time, given that the estimates on extreme empathizing in Table 5 are positive.

controls used in columns (2) and (4) of Table 4). In column (1), we include Deming's index of routine tasks, separately for each parent. Routineness of the father is strongly associated with ASD in children; a one standard deviation increase in paternal routineness is associated with an increase in ASD of 0.120 percentage points, or 6.7 percent of the mean ASD incidence. The point estimate for maternal routineness is much smaller, negative, and statistically insignificant. In column (2), we include the indices for paternal and maternal social skills, finding again that the paternal coefficient is large and statistically significant, and negative as expected. The coefficient for mothers is much smaller and statistically significant only at the 10 percent level. In column (3), we only include measures of non-routine analytical skills, and in column (4), we use measures of parents' service skills. The results in these two columns are very similar: a one standard deviation increase in paternal non-routine analytic skills (paternal service skills) is associated with a 0.043 (0.047) percentage-point decrease in ASD in children, whereas the coefficients for mothers are smaller and statistically insignificant.

While many of the estimates in columns (1) thorough (4) are of the expected sign, the negative estimate for non-routine analytical skills might be surprising at first glance. However, as shown in Table 2, non-routine analytical skills are strongly correlated with all three factors (negatively with CSF) and *social skills*. It thus captures multiple dimensions of skill. Indeed, in column (5) of Table 6, where we report results from a specification that includes all four of Deming's measures together, the coefficient estimates on non-routine analytic skills are small, positive, and statistically insignificant.

Turning to the other results in column (5), the coefficient estimates on routineness and social skills are similar to their counterparts in columns (1) and (2). In particular, having a father in an occupation with a high level of routine work is associated with an increase in the probability of ASD diagnosis in children, and having a father working in an occupation that requires strong social skills is associated with a decrease in that probability. The analogous point estimates for mothers are smaller and statistically significant only at the 10 percent level. The magnitudes of the effects for fathers are meaningful: a one standard deviation increase in paternal routineness (paternal social skills) is associated with a 5.7 (9.4) percent increase (decrease) in ASD diagnoses relative to the underlying ASD incidence. These results parallel the results in Table 4, in the sense that paternal routineness is negatively correlated with CSF. The results for *service* are difficult to interpret. We find no effect of maternal service skills, but the coefficient on paternal service skills is large and positive, contrasting sharply with the estimates in column (4). Service and social skills are highly correlated (the correlation coefficient is 0.69 in Table 2), so this may be a result of high collinearity between the two factors.

Overall, the most robust results in Table 6 point to a positive relationship between a father's routine-task skills and ASD in children, and a negative relationship between a father's social skills and ASD in children. For these two task intensity categories, we see a much smaller effect of mothers, although the point estimates have the same sign as those for fathers.

IV.5 Results by Sex of the Child

In Table 7, we report results by sex of the child, using specifications as in Equation (1). There are two motivations for splitting the sample by sex. First, ASD incidence among boys (2.65 percent) is much larger than among girls (0.85 percent). Second, our full-sample results suggest a much stronger pathway between fathers and children than between mothers and children. A simple story of a genetic link for ASD that exists primarily between fathers and their children might suggest that only boys would be affected (presumably via the *Y* chromosome).

In columns (1) and (2) of Table 7, we report results using our three factors as measures of skills for boys and girls, respectively, based on the specification in Table 4, column (2). In columns (3) and (4), we report results using Deming's measures and the specification in Table 6, column (5). The results for boys magnify the full-sample results shown previously. In particular, boys whose fathers are in occupations involving high levels of CSF or social skills are relatively unlikely to have ASD, whereas boys whose fathers are in occupations with high levels of SOF or high routineness are more likely to have ASD. Boys whose mothers have high PSF are less likely to have ASD, but the results for SOF and CSF are weak qualitatively and are statistically insignificant. For Deming's (2017) measures, only the coefficient of maternal social skills is statistically significant among the maternal measures, and only at the 10 percent level.

For girls, the point estimates are typically much smaller than for boys, although they have the same sign in all cases. They are only strongly statistically significant in the case of paternal routineness and the paternal CSF. Nonetheless, because the average ASD rate for girls is so much smaller than for boys, the magnitude of the effects in percentage terms is similar across girls and boys. For example, the coefficient on paternal CSF for boys implies that a one standard deviation increase in a father's CSF is associated with a decrease of 3.5 percent (= -0.093 / 2.645) in the probability of a boy having ASD; for girls, the corresponding decrease is 3.7 percent (= -0.032 / 0.850).

Our finding that paternal skills – especially CSF and routineness of fathers – are important for both boys and girls in the intergenerational transmission of ASD is not consistent with a genetic pathway that involves simple transmission through *Y* chromosomes. Indeed, the underlying genetics behind ASD are complex; studies such as Krishnan et al. (2016) estimate that ASD is driven by an interaction of several hundred different genes. Studies have also suggested that even if females have the same ASD-causing genes as males, those genes are less likely to be expressed in females (Zhang et al., 2020), potentially explaining the divergence in male and female rates of ASD.

IV.6 The Relative Contributions of Maternal and Paternal Skills

The bulk of our estimates thus far provide suggestive evidence that paternal occupation-based skills are more strongly associated with childhood ASD than are maternal skills. However, as noted above, the impacts of maternal skills might be difficult to measure because labor market barriers likely distort female occupational choices and participation decisions. In order to address these concerns, we turn next to specifications in which we use occupational information for maternal and paternal grandfathers of the children in our sample, rather than the corresponding measures for parents. Table 8, which mirrors our preferred specifications in Tables 4 and 6, presents the estimates.

Unfortunately, the estimates in Table 8 are largely uninformative, as most are neither practically nor statistically significant. For example, only one of the estimates in column (1) is (barely) statistically distinguishable from zero at the ten percent level. In comparison to the estimates in Tables 4 and 6, those in Table 8 are both imprecisely estimated and attenuated toward zero, especially for paternal grandfathers relative to fathers. Two factors are likely responsible. First, we only have grandfathers' information for roughly 50 percent of the children. Second, and perhaps more importantly, generation skipping potentially dilutes the importance of traits that pass from parents to children. As such, we are wary of drawing firm conclusions about the relative contributions of paternal and maternal skills based on these results.[31]

Another potential reason why we find smaller effects for mothers than for fathers in our preferred specifications is that mothers might be more likely to have jobs that bring them into regular contact with children (e.g., child care workers) or have specialized knowledge that make them more aware of the symptoms of ASD (e.g., pediatricians). More generally, if parents in these fields are more likely to notice that their child has symptoms of ASD, the resulting

[31] We have also produced versions of Tables 4-7 for the subsample of children (and their parents) who appear in Table 8. The results (unreported) are similar to the full-sample results.

associations between our skill measures and ASD could capture increased diagnosis net of underlying incidence, rather than a genetically inheritable link between parental and child traits. To address this possibility, we estimated specifications in which we exclude children who have parents in such occupations (doctors, secondary school teachers, primary and pre-school teachers and associates, and child-care workers). The estimates, available upon request, are similar to those shown above in Tables 4-7, in that they point to larger roles of paternal skills than maternal skills, at least for the occupation-based skills we consider.

V. Discussion and Conclusions

Using large-scale administrative data in Denmark, we test the hypothesis that parental skills are systematically related to diagnoses of autism spectrum disorder (ASD) in children. We construct measures of maternal and paternal skills based on occupational choices in order to assess the association between parental skills and ASD in children.

We focus on the first three factors from a factor analysis of O*NET Skills and Abilities, and we find evidence of a link between skills – especially paternal skills – and ASD in children. In particular, for fathers, the second factor, which is related to the use of systems and ordering in occupations, is positively related to diagnoses of ASD in children, whereas the opposite is true for the third factor, which is related to communication skills. Analogous estimates for maternal skills for these second and third factors tend to be smaller and statistically insignificant (and sometimes opposite-signed of those for fathers). The first factor, which captures general professional skills for both mothers and fathers, is negatively related to ASD diagnoses among children.

We also find strong associations between ASD diagnoses and Deming’s (2017) measures of social skills and routineness. Again, fathers’ characteristics appear to play much stronger roles than do mothers’ characteristics. While social skills are positively related to the

Professional Skills and Communication Skills Factors, routineness is negatively correlated with them, providing some insight into why these results emerge. The roles of Deming's other two measures – non-routine analytic skills and service skills – are less clear, as the relevant estimates differ considerably across specifications.

In addition, we find evidence consistent with the theory that ASD is a manifestation of extreme personality traits. For example, we find that a child with two parents who are characterized as "extreme systemizers" has a roughly 35 percent higher likelihood of ASD diagnosis compared to children whose parents both have "balanced brain types", using the terminology of Baron-Cohen (2004).

Finally, while we find clear evidence of assortative mating based on all of the measures we use, we are unable to detect a role for assortative mating on ASD incidence. The estimated coefficients on interaction terms between mothers' and fathers' skills are consistently small and statistically indistinguishable from zero. Moreover, assortative mating along these dimensions has not risen over the 13 cohorts of children we study, even though ASD rates in Denmark doubled during this period. Thus, we conclude that intertemporal patterns of assortative mating on these skills are unlikely drivers of the dramatic increase in ASD diagnoses in recent decades.

Taken together, our results lend credence to the idea that skills are heritable and can lead to ASD (and potentially other outcomes) in children. Our findings suggest that the pathway by which this occurs is primarily through fathers, although we do not completely rule out the possibility of a maternal pathway. Further, our findings show that it is possible to use occupational choices to identify proxies for parental traits more generally, highlighting the potential uses of large-scale administrative data on parental characteristics to shed light on the transmission of traits from parents to their children.

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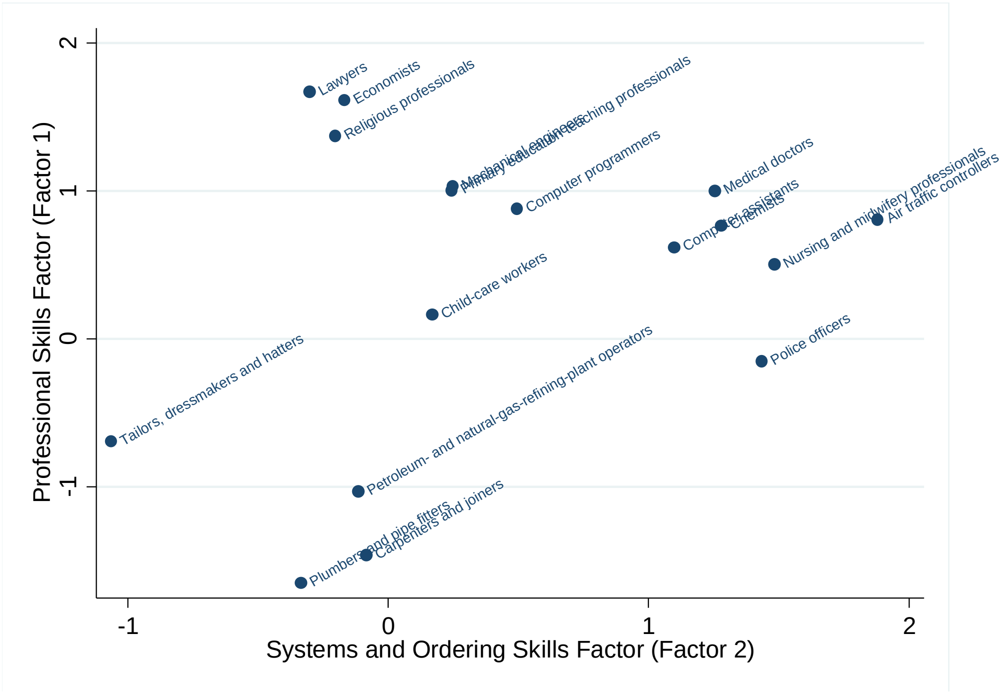
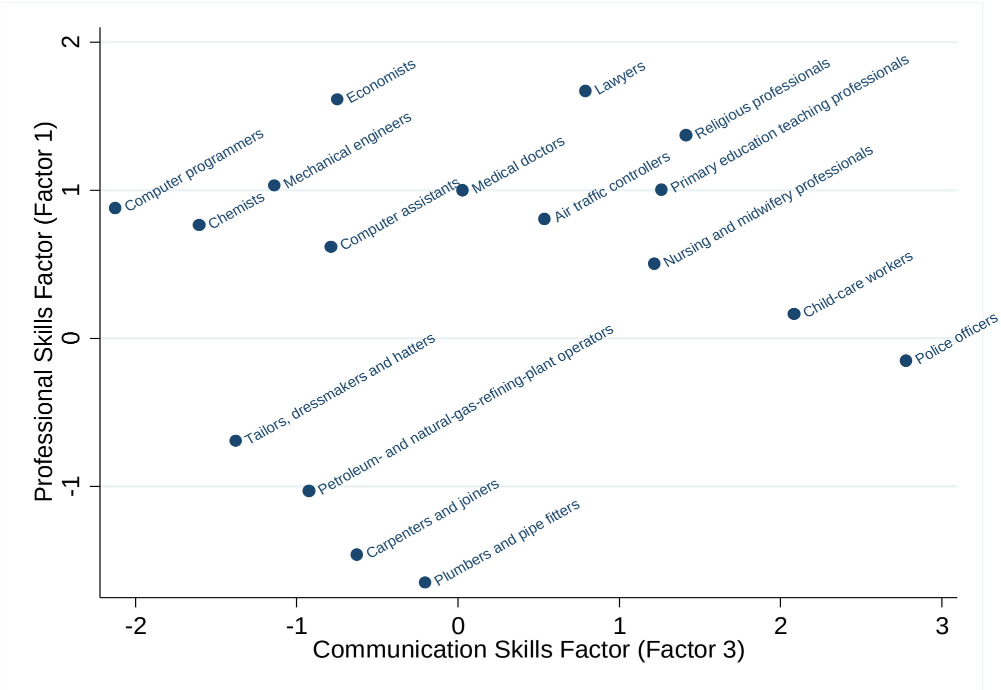
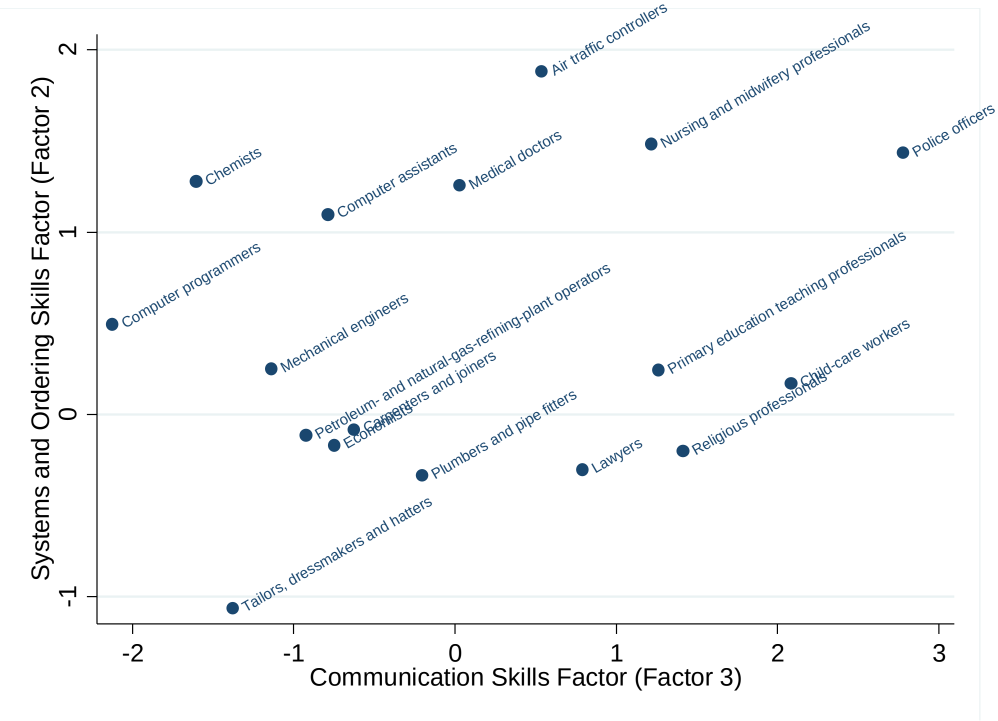
Figure 1: Factor Scores for Selected ISCO-88 Occupations

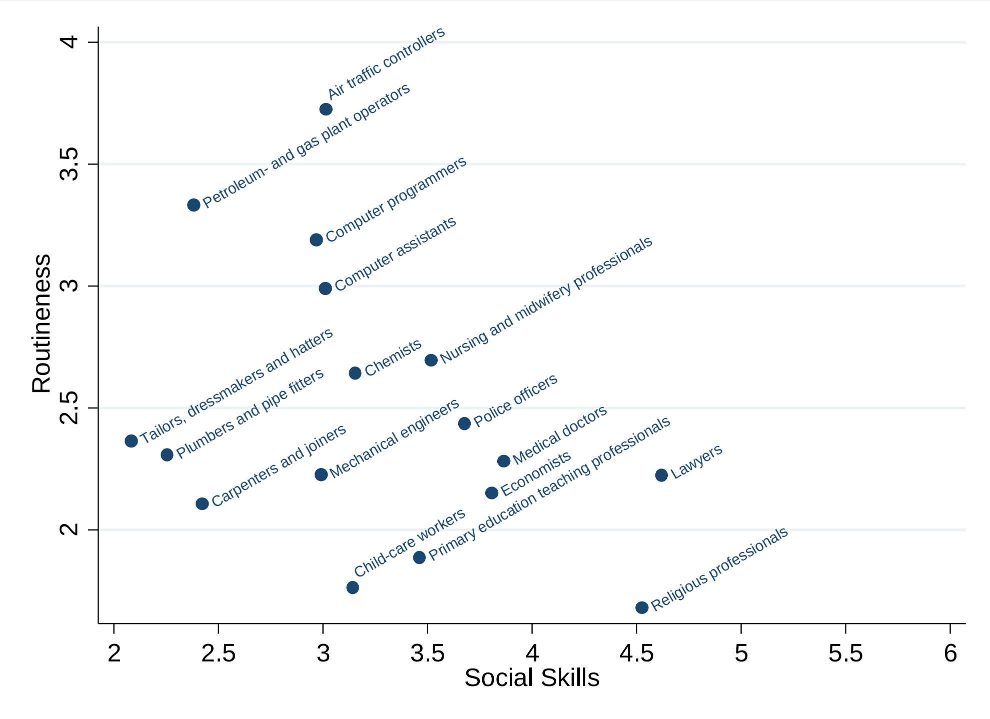


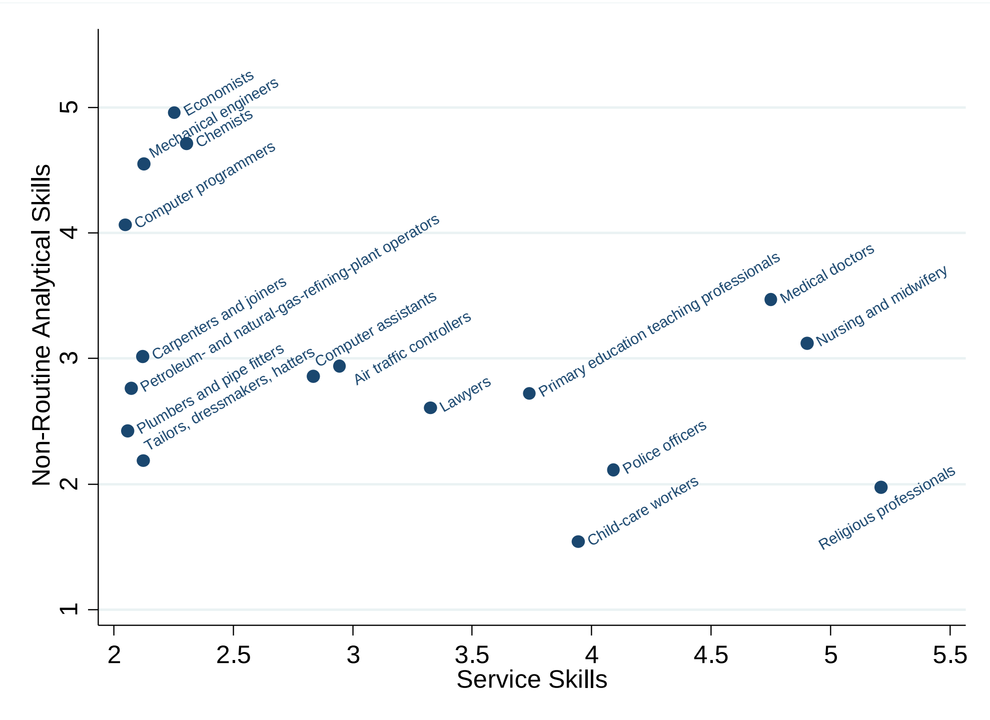




Notes: The figure shows examples of standardized factor scores for each labeled occupation. Description of each factor is in the main text in Section II.I.

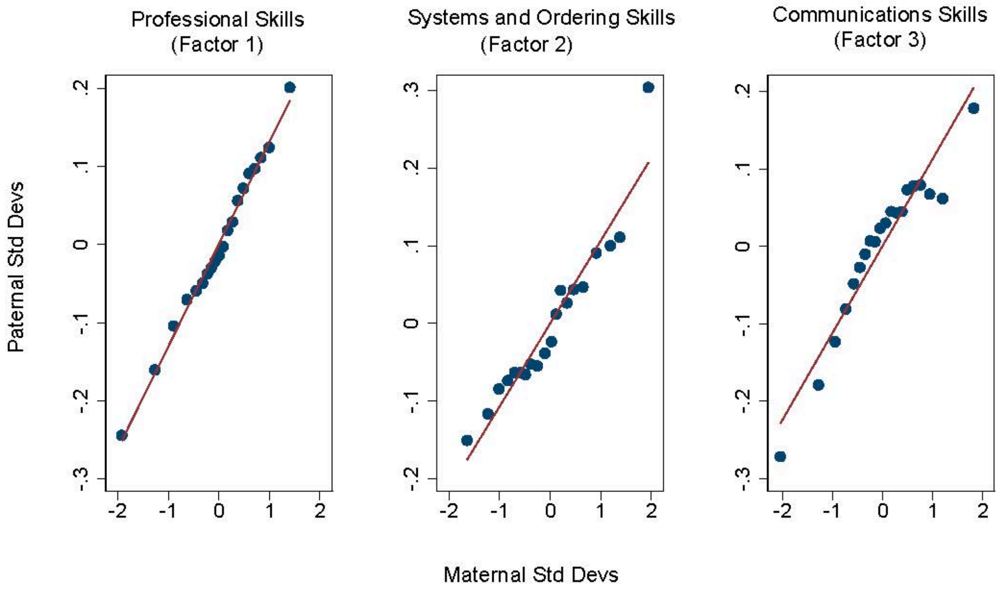
Figure 2: Deming (2017) Measures for Selected ISCO-88 Occupations





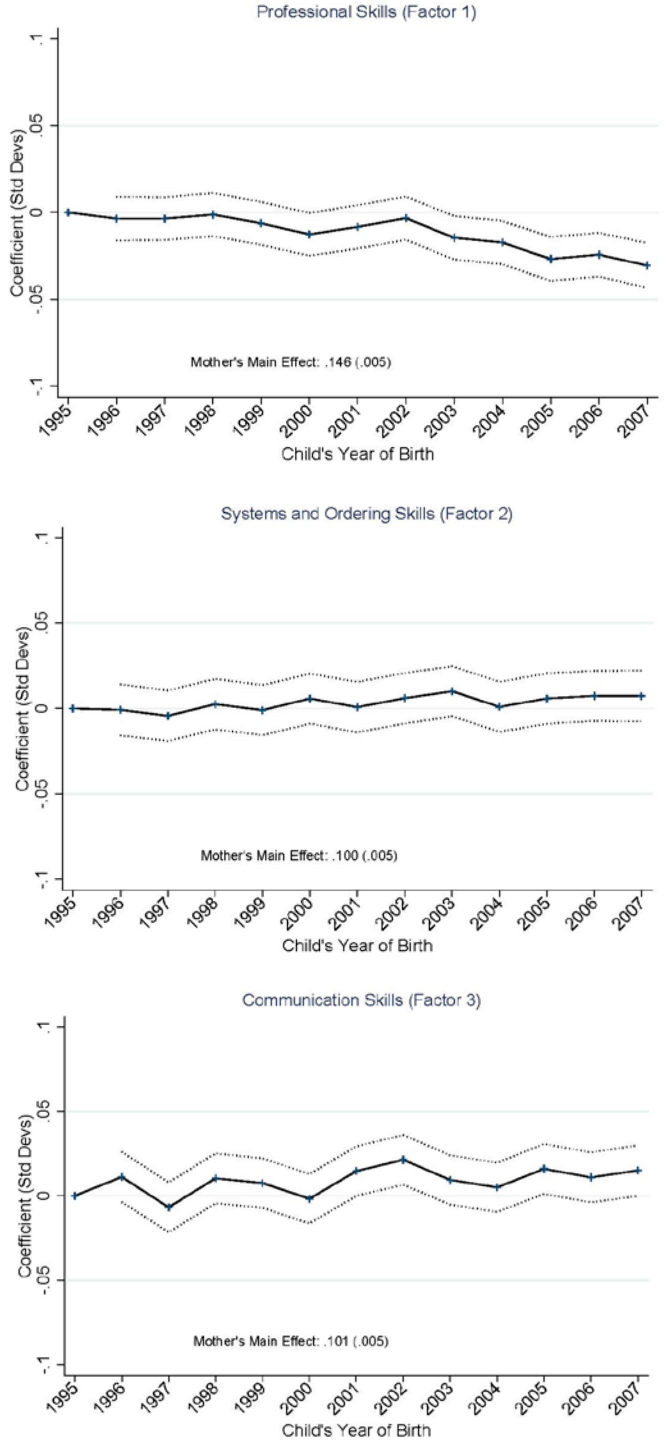
Notes: The top panel shows averages of Deming's (2017) *routineness* and *social skills* measures for each labeled occupation, while the bottom panel shows averages of the *non-routine analytical skills* and *service skills* measures for those same occupations.

Figure 3: Cross-Sectional Assortative Mating by Skill Factors



Notes: Each panel shows binscatters of father's and mother's Skill Factors, residualized with respect to child's sex, parents' age, mother's marital status, child's birth year, parents' educational attainment, parental income history from ages 25 through 34 (as described in Section IV), and parish of birth fixed effects. Each panel shows the same measure for each parent; the *X*-axis measures standardized units of the relevant maternal measure, and the *Y*-axis measures standardized units of the relevant paternal measure. The solid lines in each panel represent linear fits from OLS regressions of the relevant paternal measure on the relevant maternal measure.

Figure 4: Changes in Assortative Mating on Residualized Factors over Time



Notes: Each panel shows coefficient estimates and 95% confidence intervals from the interaction of birth cohort and maternal residualized factors (PSF, SOF, and CSF) in linear models of paternal measures on those interactions. See Equation (2) in the text for more details. We residualized each factor with respect to child's sex, parents' age, mother's marital status, child's birth year, parents' educational attainment, parental income history from ages 25 through 34, and municipality fixed effects.

Table 1: Highest and Lowest Loadings for Principal Factors of Importance Scores

Factor 1 (48%)		Factor 2 (19%)		Factor 3 (9%)	
A. Highest 10 Loadings					
Social Perceptiveness	0.034	Reaction Time	0.069	Social Perceptiveness	0.099
Speaking	0.034	Troubleshooting	0.068	Peripheral Vision	0.093
Oral Expression	0.034	Operation Monitoring	0.063	Stamina	0.092
Active Learning	0.033	Flexibility of Closure	0.055	Oral Expression	0.085
Inductive Reasoning	0.028	Inductive Reasoning	0.053	Speaking	0.077
Critical Thinking	0.027	Peripheral Vision	0.051	Gross Body Coordination	0.075
Written Expression	0.027	Systems Analysis	0.049	Oral Comprehension	0.063
Oral Comprehension	0.027	Equipment Selection	0.048	Response Orientation	0.062
Reading Comprehension	0.026	Perceptual Speed	0.048	Speech Clarity	0.057
Writing	0.025	Systems Evaluation	0.047	Spatial Orientation	0.056
B. Lowest 5 Loadings					
Dynamic Strength	-0.028	Explosive Strength	0.002	Complex Problem Solving	-0.067
Extent Flexibility	-0.032	Trunk Strength	0.002	Operations Analysis	-0.074
Reaction Time	-0.032	Rate Control	-0.001	Equipment Selection	-0.084
Repairing	-0.034	Programming	-0.003	Mathematical Reasoning	-0.094
Manual Dexterity	-0.044	Speaking	-0.008	Troubleshooting	-0.099

Notes: Cell entries are estimates of the scores of predictions using the first, second, and third factors. We first performed factor analysis on all 87 Skills and Abilities across all occupations in the O*Net dataset, as described in the text.

Table 2: Correlations Across SOC Occupation Codes of Factors and Deming (2017) Measures

	PSF	SOF	CSF	Routineness	Social Skills	Non-Routine Analytical
PSF	-	-	-	-	-	-
SOF	0.05	-	-	-	-	-
CSF	0.08	0.06	-	-	-	-
Routineness	-0.20	0.01	-0.30	-	-	-
Social Skills	0.87	0.28	0.28	-0.33	-	-
Non-Routine Analytical	0.64	0.43	-0.40	0.01	0.57	-
Service Skills	0.59	0.09	0.50	-0.27	0.69	0.15

Notes: Descriptions of PSF, SOF, CSF, Routineness, Social Skills, Non-Routine Analytical, and Service Skills are in the main text in Section II.

Table 3: Summary Statistics

	(1)	(2)	(3)
	All Children	Child with ASD	Child without ASD
Panel A: Child and Parent Characteristics			
Diagnosed with ASD	0.017	-	-
	(0.130)	-	-
Diagnosed with ASD by Age 8	0.009	0.443	-
	(0.094)	(0.497)	-
Child is Female	0.487	0.227	0.491
	(0.500)	(0.419)	(0.500)
Mother is Married at Child's Birth	0.593	0.562	0.594
	(0.491)	(0.496)	(0.491)
Father's Age at Child's Birth	32.3	31.6	32.3
	(4.6)	(4.6)	(4.6)
Mother's Age at Child's Birth	30.3	29.6	30.3
	(4.3)	(4.5)	(4.3)
Father's Education - Bachelor's Degree or Higher	0.292	0.251	0.293
	(0.455)	(0.433)	(0.455)
Father's Education - Some Post-HS Education	0.570	0.567	0.570
	(0.495)	(0.495)	(0.495)
Father's Education - High School or Less	0.138	0.182	0.137
	(0.345)	(0.386)	(0.344)
Mother's Education - Bachelor's Degree or Higher	0.425	0.376	0.426
	(0.494)	(0.485)	(0.495)
Mother's Education - Some Post-HS Education	0.475	0.489	0.475
	(0.499)	(0.500)	(0.499)
Mother's Education - High School or Less	0.100	0.134	0.099
	(0.300)	(0.340)	(0.299)
Panel B: Factor measures of Parents (Standardized)			
Father's PSF	0.031	-0.064	0.033
	(0.999)	(0.969)	(1.000)
Father's SOF	0.014	0.016	0.014
	(0.998)	(0.999)	(0.998)
Father's CSF	-0.015	-0.021	-0.015
	(1.001)	(1.03)	(1.001)
Mother's PSF	0.023	-0.100	0.025
	(0.983)	(0.997)	(0.982)
Mother's SOF	0.008	-0.044	0.009
	(0.993)	(0.971)	(0.993)
Mother's CSF	-0.001	0.039	-0.002
	(1.000)	(1.018)	(1.000)

Panel C: Deming (2017) Scores of Parents (Standardized)

Father's Routineness	-0.005	0.102	-0.007
	(0.998)	(1.014)	(0.998)
Father's Social Skills	0.025	-0.091	0.027
	(0.999)	(0.952)	(0.999)
Father's Non-Routine Analytic Skills	0.035	-0.062	0.037
	(0.997)	(0.995)	(0.997)
Father's Service Skills	0.008	-0.032	0.009
	(1.002)	(0.990)	(1.003)
Mother's Routineness	-0.000	0.022	-0.001
	(0.998)	(1.005)	(0.998)
Mother's Social Skills	0.013	-0.101	0.015
	(0.991)	(0.969)	(0.991)
Mother's Non-Routine Analytic Skills	0.013	-0.070	0.014
	(0.996)	(0.990)	(0.996)
Mother's Service Skills	0.005	-0.034	0.006
	(0.997)	(0.986)	(0.997)
Observations	738,917	12,646	726,271

Notes: Means with standard deviations provided in parentheses. All measures in Panels B and C are standardized within gender. ICD-10 diagnostic codes for ASD include F84.0, F84.1, F84.5, F84.8, and F84.9. We consider a child as having ASD if he or she is diagnosed by the end of our observation period (which ranges from 5 to 19 years old). Indicators for diagnosis by a given age are restricted only to those cohorts that are observed for the entirety of the relevant age span.

Table 4: The Association of ASD with Measures of Parental Skills as Measured by O*NET Skills and Abilities Factors

	(1)	(2)	(3)	(4)
Paternal PSF	-0.088***	-0.032	-0.087***	-0.033
	(0.021)	(0.022)	(0.021)	(0.022)
Maternal PSF	-0.139***	-0.058**	-0.141***	-0.058**
	(0.024)	(0.025)	(0.024)	(0.025)
Paternal SOF	0.024	0.042***	0.023	0.041***
	(0.015)	(0.015)	(0.014)	(0.015)
Maternal SOF	-0.022	-0.006	-0.021	-0.007
	(0.018)	(0.018)	(0.018)	(0.018)
Paternal CSF	-0.029**	-0.062***	-0.031**	-0.063***
	(0.014)	(0.014)	(0.014)	(0.014)
Maternal CSF	0.089***	0.030*	0.088***	0.032*
	(0.018)	(0.018)	(0.018)	(0.018)
Paternal × Maternal PSF			-0.012	0.004
			(0.019)	(0.019)
Paternal × Maternal SOF			-0.016	-0.006
			(0.014)	(0.014)
Paternal × Maternal CSF			0.012	0.015
			(0.015)	(0.015)
Observations	738,892	738,892	738,892	738,892
Income controls		X		X

Notes: Cell entries are estimates from linear probability models of ASD diagnoses. Sample size is 738,892 in all specifications. Mean ASD incidence is 1.71 percent in all specifications. Section II includes the Descriptions of the Factors. Controls include gender of the child, parental age, marital status of parents at birth, indicators of parental field of study, parental income history between ages 25 and 34, cohort fixed effects and parish of birth fixed effects. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered at the birth cohort and parental education level.

Table 5: Assessing Extreme-Brain Theories of ASD Using Principal Factors of Skill

	Without Factor Main Effects (1)		Including Factor Main Effects (2)	
	Paternal	Maternal	Paternal	Maternal
	(a)	(b)	(a)	(b)
Extreme Empathizing	0.088	0.468**	0.040	0.260
(*SOF – CSF*) *<= -2*	(0.070)	(0.218)	(0.101)	(0.241)
Empathizing	0.103**	0.165***	0.086	0.051
(*SOF – CSF*) *between -1 and -2*	(0.041)	(0.041)	(0.060)	(0.060)
Systemizing	0.185***	-0.000	0.222***	0.090
(*SOF – CSF*) *between 1 and 2*	(0.047)	(0.051)	(0.072)	(0.067)
Extreme Systemizing	0.376***	0.217***	0.450***	0.458***
(*SOF – CSF*) *>= -2*	(0.047)	(0.057)	(0.108)	(0.124)
PSF (Linear)	-	-	-0.046**	-0.040
	-	-	(0.022)	(0.025)
SOF (Linear)	-	-	-0.042	-0.078**
	-	-	(0.036)	(0.037)
CSF (Linear)	-	-	0.005	0.089**
	-	-	(0.035)	(0.040)

Notes: Cell entries are estimates from linear probability models of ASD diagnoses as a function of “brain types” as described by Baron-Cohen (2003). For example, in the first column the “Paternal Extreme Empathizing” indicator equals 1 if the father's SOF index lies more than 2 standard deviations below the father's CSF index, the “Paternal Empathizing” indicator equals 1 if the father's CSF index lies between 1 and 2 standard deviations above the father's SOF index, and so on. The excluded category is the "balanced brain", in which the father's SOF and CSF indices lie within one standard deviation of each other. Sample size is 738,836 in all specifications. Mean ASD incidence is 1.77 percent in all specifications. Controls include gender of the child, parental age, marital status of parents at birth, indicators of parental field of study, parental income history between ages 25 and 34, cohort fixed effects and parish of birth fixed effects. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered at the birth cohort and parental education level.

Table 6: The Association of ASD with Skills, as Measured by Deming's (2017) Skill Indices

	(1)	(2)	(3)	(4)	(5)
Paternal Routineness	0.120***				0.103***
	(0.019)				(0.020)
Maternal Routineness	-0.028				-0.048*
	(0.019)				(0.025)
Paternal Social Skills		-0.130***			-0.166***
		(0.018)			(0.030)
Maternal Social Skills		-0.034*			-0.063*
		(0.020)			(0.036)
Paternal Non-routine Analytic Skills			-0.043**		0.024
			(0.018)		(0.022)
Maternal Non-routine Analytic Skills			-0.027		0.014
			(0.020)		(0.030)
Paternal Service Skills				-0.047***	0.088***
				(0.016)	(0.024)
Maternal Service Skills				-0.015	0.006
				(0.020)	(0.031)

Notes: Sample size is 738,917 in all specifications. Mean ASD incidence is 1.71 percent in all specifications. Controls include gender of the child, parental age, marital status of parents at birth, indicators of parental field of study, parental income history between ages 25 and 34, cohort fixed effects and parish of birth fixed effects. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered at the birth cohort and parental education level.

Table 7: The Association of ASD with Measures of Parental Skills, by Gender of the Child

	Using Principal Factors of Skills			Using Deming's measures	
	Male	Female		Male	Female
	(1)	(2)		(3)	(4)
Paternal PSF	-0.029	-0.032	Paternal Routineness	0.153***	0.054***
	(0.035)	(0.02)		(0.031)	(0.020)
Maternal PSF	-0.089**	-0.020	Maternal Routineness	-0.066	-0.029
	(0.04)	(0.023)		(0.043)	(0.023)
Paternal SOF	0.066**	0.013	Paternal Social Skills	-0.271***	-0.056*
	(0.026)	(0.016)		(0.051)	(0.032)
Maternal SOF	-0.011	-0.000	Maternal Social Skills	-0.107*	-0.010
	(0.031)	(0.017)		(0.060)	(0.036)
Paternal CSF	-0.093***	-0.032**	Paternal Non-routine Analytic Skills	0.053	-0.003
	(0.026)	(0.016)		(0.039)	(0.025)
Maternal CSF	0.044	0.016	Maternal Non-routine Analytic Skills	0.027	0.000
	(0.030)	(0.018)		(0.053)	(0.029)
			Paternal Service Skills	0.163***	0.012
				(0.042)	(0.025)
			Maternal Service Skills	0.024	-0.014
				(0.052)	(0.026)
Observations	379,136	359,756		379,149	359,768
Mean Dep.	2.645	0.850		2.645	0.850

Notes: Controls include gender of the child, parental age, marital status of parents at birth, indicators of parental field of study parental income history between ages 25 and 34, cohort fixed effects and parish of birth fixed effects. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors are clustered at the birth cohort and parental education level.

Table 8: The Association of ASD with Measures of Grandfathers' Skills

	Using Principal Factors of Skills		Using Deming's Measures				
	(1)		(2)	(3)	(4)	(5)	(6)
Paternal PSF	-0.036	Paternal Routineness	0.037*				0.028
	(0.022)		(0.020)				(0.022)
Maternal PSF	-0.034*	Maternal Routineness	0.017				0.013
	(0.021)		(0.020)				(0.022)
Paternal SOF	0.014	Paternal Social Skills		-0.051**			-0.070
	(0.020)			(0.021)			(0.043)
Maternal SOF	-0.020	Maternal Social Skills		-0.070***			-0.112***
	(0.021)			(0.020)			(0.040)
Paternal CSF	-0.027	Paternal Non-routine Analytic Skills			-0.023		0.016
	(0.019)				(0.021)		(0.032)
Maternal CSF	0.002	Maternal Non-routine Analytic Skills			-0.053**		0.008
	(0.019)				(0.021)		(0.029)
		Paternal Service Skills				-0.034*	0.022
						(0.020)	(0.033)
		Maternal Service Skills				-0.022	0.058*
						(0.020)	(0.033)
Observations	422,103		422,422	422,422	422,422	422,422	422,422

Notes: Controls include gender of the child, parental age, marital status of parents at birth, indicators of parental field of study, parental income history between ages 25 and 34, cohort fixed effects and parish of birth fixed effects. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Dependent variable mean = 1.71 in all specifications. Standard errors are clustered at the birth cohort and parental education level.

Appendix A. Autism Diagnosis and Service Provision in Denmark

Most Danish health care services, including the diagnostic evaluations and treatment of ASD, are free of charge to all citizens (Danish Ministry of Health and Prevention, 2008). There is strong evidence (Kraznik et al., 1997) that differences in health drive overall healthcare utilization rather than differences in geography or demographics (other than gender).

If parents or other caregivers notice that a child is not following the typical developmental path, they may request that the child be evaluated by a medical professional. The first step in the diagnosis of very young children often involves a visit to the general practitioner, who acts as a gatekeeper for specialist treatment.[32] The general practitioner discusses the caregiver's concerns, collects information on the child's medical history (e.g., prenatal and perinatal conditions, hereditary dispositions), and conducts a preliminary assessment of the child's development, focusing on criteria outlined by the *International Classification of Diseases* (ICD) diagnostic manual. If the general practitioner's initial evaluation raises concerns about a mental health problem, the child is referred from primary care to specialist care. Given that there are no screening tools that can unequivocally detect ASD, the medical guidelines recommend that all children with suspected ASD be referred to a specialist (Sundhedsstyrelsen, 2001).

A child who is referred to specialist care is evaluated by an interdisciplinary team that consists of a child and adolescent psychiatrist, a clinical or educational psychologist, and often a speech and language therapist.[33] Parents usually have very limited power in choosing the specialist due to long waiting times. According to Daley et al. (2015), until the 2000s, "it was not uncommon for children to wait up to two years to be seen in regional child and adolescent psychiatry departments" [p. 19]. Even in recent years, waiting times remain an important problem: in 2005, 35 percent of children had to wait at least 3 months before their first psychiatric evaluation, and 1 percent had to wait more than a year (Sundhedsstyrelsen, 2015).

[32] School-age children are typically referred to a specialist by school psychologists.

[33] Children referred to specialists can be treated by psychiatrists at regional psychiatric hospitals or in private practice (under contract with the Danish Regions). General practitioners refer patients to private practices only if regional hospitals are overbooked. Hence, the bulk of child and adolescent psychiatric care is provided by regional hospitals. Currently, only 16 private psychiatry practices have formal agreements with the Danish Regions. These private practices cared for 4,049 patients in 2011. Hospital-based psychiatric wards, on the other hand, provided care for 22,788 children in the same year. It is possible to see a specialist without a referral, but these specialists work at private psychiatric clinics that do not contract with the Danish regions. In this case, patients have to cover the fees of these providers out of pocket. For more details on the structure and organization of mental health services in Denmark, see Chapter 3 in Daley et al. (2015).

The assessment by the interdisciplinary team includes a structured observation, a diagnostic interview, a psychological examination, and a medical examination.[34] Structured observation refers to a 30-60 minute evaluation of the child in which the examiner assesses the child's social and communication skills through a series of structured and semi-structured tasks. The assessment uses autism-specific instruments, such as Autism Diagnostic Observation Schedule (ADOS). The diagnostic interview involves collecting the child's full developmental history through a structured interview of the parents.[35] The purpose of the psychological examination is to create a cognitive profile of the child and to examine the child's learning strategies.[36] Finally, the team conducts a physical examination.[37] A diagnosis of ASD is made if the child presents developmental and behavioral features consistent with criteria outlined by the *International Classification of Diseases*.

Children who are diagnosed with ASD are entitled to free medical care. ASD care is tailored to the specific needs of each child and consists of behavioral therapy and pharmaceutical treatment. The pedagogical and psychological treatments provided to children aim to help them acquire new skills and to ultimately function independently in everyday life. Therapies for children with severe developmental delays focus on language development and skills such as imitation, attention, and play and exchange. Treatment of high functioning ASD children targets other skills such as social interactions and self-help. While there are no specific pharmaceutical drugs used in treatment of ASD, children with ASD receive pharmaceutical treatment for psychiatric and somatic comorbidities (such as depression and ADHD). In rare cases, children may be prescribed antipsychotic drugs to address aggressive behavior.[38]

Children with ASD are also eligible to receive special education. The type of special education is determined in consultation with the child's parents after the psychological assessment. If the child needs fewer than 9 hours of special needs education per week, (s)he is placed in mainstream classrooms with pullout time with a special needs teacher. If the child needs at least 9 hours of special needs education per week, then instruction takes place in remedial classes or at a special-needs school.

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[34] For a description of autism care in Denmark, see Videnscenter for Autisme (2006).

[35] Medical guidelines in Denmark recommend the interview to involve autism-specific tools, such as the Autism Diagnostic Interview-Revised (ADI-R).

[36] Different neuropsychological tests are used depending on the child's level of development and language impairment.

[37] The medical exam always includes a measurement of head circumference and a screening for sensory defects, but it can also include an examination of vision and hearing and an assessment of signs of specific comorbidities associated with ASD (e.g., neurological examination for epilepsy, examination of the skin for tuberous sclerosis).

[38] In Denmark, Risperidone is the only antipsychotic drug currently approved for treatment of aggressiveness in children with ASD, and only for children who are at least 6 years old.

Finally, parents of children with ASD can apply for government support in accordance with the Danish Social Service Act. While parents are generally provided some counseling when a child receives a diagnosis of ASD, they can ask for additional funds to enroll in courses to understand their child's behavior, to create a family environment conducive to their child's progress, and to deal with the stress of caring for a disabled child. They can also request compensation to cover the direct costs of caring for a child with ASD (e.g., technical equipment needed at home, additional costs associated with special dietary restrictions, or additional costs associated with hired professional help) as well as compensation for lost earnings. Finally, parents can request to have non-financial resources, such as professional childcare at specialized institutions.

Appendix B. Descriptions of O*NET Skills and Abilities Used in the Construction of EQ and SQ Indices

In order to consider a link between the three main factors we identify in the factor analysis of O*NET skills and abilities and conceptualizations in the psychiatric literature of systemizing and empathizing, we created a concordance between the individual skills and abilities in the O*NET and the (non-filler) questions in in both of the EQ and SQ-R questionnaires in psychology (Baron-Cohen and Wheelwright, 2004; Wheelwright et al., 2006).We did this by making a determination about whether an individual with a specific skill or ability in the O*NET would respond with either "agree" or "strongly agree" to each item in the questionnaires. For example, consider the skill of *social perceptiveness,* defined in the O*NET as "Being aware of others' reactions and understanding why they react as they do." We determined that a person with *social perceptiveness* would have "agreed" or "strongly agreed" with 23 of the 40 non-filler items in the modified EQ questionnaire, so we assigned *social perceptiveness* an EQ value of 23.

We found that one additional *ability* and six *skills* mapped well with the modified EQ questionnaires. They are, respectively: *problem sensitivity* ("the ability to tell when something is wrong or is likely to go wrong. It does not involve solving the problem, only recognizing that there is a problem"), *active listening* ("giving full attention to what other people are saying, taking time to understand the points being made, asking questions as appropriate, and not interrupting at inappropriate times"), *instructing* ("teaching others how to do something"), *negotiation* ("bringing others together and trying to reconcile differences"), *persuasion* ("persuading others to change their minds or behavior"), *service orientation* ("actively looking for ways to help people"), and *speaking* ("talking to others to convey information effectively"). We assigned values to all of these skills and abilities based on the number of questions in the modified EQ questionnaire that we associated with them. In Panel A of Table A2, we provide the number of questions in the modified EQ questionnaire to which each *ability* and *skill* has been associated (that number is zero for all *abilities* and *skills* not shown in the table).

The SQ measure we use is a composite measure of ten *abilities* and eight *skills*. The *abilities* are: *category flexibility* (defined as "the ability to generate or use different sets of rules for combining or grouping things in different ways", *deductive reasoning* (defined as "The ability to apply general rules to specific problems to produce answers that make sense"), *flexibility of closure* ("The ability to identify or detect a known pattern (a figure, object, word, or sound) that is hidden in other distracting material"), *inductive reasoning* (defined as "the ability to combine pieces of information to form general rules or conclusions -includes finding a relationship among seemingly unrelated events”), *information ordering* (defined as “the ability to arrange things or actions in a certain order or pattern according to a specific rule or set of rules ,e.g., patterns of numbers, letters, words, pictures, mathematical operations), *mathematical reasoning* (defined as “the ability to choose the right mathematical methods or formulas to solve a problem”), *memorization* (defined as “the ability to remember information such as words, numbers, pictures, and procedures”), *number facility* (defined as “the ability to add, subtract, multiply, or divide quickly and correctly”), *spatial orientation* (defined as “the ability to know your location in relation to the environment or to know where other objects are in relation to you”), *visualization* (defined as “the ability to imagine how something will look after it is moved around or when its parts are moved or rearranged”). The eight skills are: *equipment maintenance* (defined as “performing routine maintenance on equipment and determining when and what kind of maintenance is needed”), *equipment selection* (defined as “determining the kind of tools and equipment needed to do a job”), *installation* (defined as “installing equipment, machines, wiring, or programs to meet specifications”), *management of financial resources* (defined as “determining how money will be spent to get the work done, and accounting for these expenditures”), *repairing* (defined as “repairing machines or systems using the needed tools”), *science* (defined as “using scientific rules and methods to solve problems”), *time management* (defined as “managing one’s own time and the time of others”), *troubleshooting* (defined as “determining causes of operating errors and deciding what to do about it”). In Table A2, we provide a full list of the skills and abilities that we matched to the SQ and EQ questions, and the SQ and EQ values that correspond to the number of questions to which they matched for each test.

We then use these SQ and EQ values to construct overall SQ and EQ indexes for each occupation. To do this, we also make use of the importance scores in O*NET for each ability and skill, allowing us to place more weight for each occupation on skills and abilities that O*NET has determined are more important for the occupation. O*NET assigns these importance scores based on data collected from answers to a version of the question “*How important is the ability/skill to the occupation?*” with answers given on a scale from 1 (“not important”) to 5 (“extremely important”).

Our calculated value of the EQ index for occupation *j* is:

(1) $$EQ_j = \frac{1}{K}\sum_k Value_k^{EQ} \times IM_{kj},$$

where $Value_k^{EQ}$ is the value we assigned to skill/ability *k*, and IM_{kj} is the O*NET importance score of skill/ability *k* in occupation *j*. As an example, consider the O*NET occupation "Child, Family, and School Social Workers." O*NET lists the skill of *social perceptiveness* to have an importance score of 4.12 for this occupation, and as described above, we assigned social perceptiveness an EQ value of 23. Thus, the contribution of social perceptiveness to the overall EQ index for this occupation is 23 × 4.12 = 94.76. We average these products over all skills/abilities *k* for the "Child, Family, and School Social Workers" occupation to calculate the overall occupational EQ index. We construct the SQ measure for each occupation *j* in a similar fashion:

(2) $$SQ_j = \frac{1}{K} \sum_k Value_k^{SQ} \times IM_{kj},$$

where $Value_k^{SQ}$ is the value we assigned to skill/ability *k* based on our concordance of the skill/ability to the modified SQ-R questionnaire (see Table A2).

Table A1: Factor Loadings of Importance Scores for O*NET Skills and Abilities

Skill / Ability:	Normalized Factor Loadings on Factor 1 (1)	Factor 2 (2)	Factor 3 (3)
Active Learning	0.033	0.031	-0.018
Active Listening	0.015	0.006	0.034
Arm-Hand Steadiness	-0.020	0.043	-0.038
Auditory Attention	-0.005	0.030	0.042
Category Flexibility	0.011	0.029	-0.016
Complex Problem Solving	0.024	0.045	-0.067
Control Precision	-0.020	0.026	-0.030
Coordination	0.008	0.019	0.042
Critical Thinking	0.027	0.036	-0.005
Deductive Reasoning	0.022	0.039	-0.021
Depth Perception	-0.014	0.046	0.026
Dynamic Flexibility	-0.010	0.013	0.013
Dynamic Strength	-0.028	0.030	0.021
Equipment Maintenance	-0.016	0.021	-0.010
Equipment Selection	-0.007	0.048	-0.084
Explosive Strength	-0.010	0.002	0.012
Extent Flexibility	-0.032	0.023	0.028
Far Vision	-0.002	0.047	0.027
Finger Dexterity	-0.009	0.027	-0.030
Flexibility of Closure	0.000	0.055	-0.007
Fluency of Ideas	0.021	0.035	-0.025
Glare Sensitivity	-0.014	0.016	0.055
Gross Body Coordination	-0.028	0.031	0.075
Gross Body Equilibrium	-0.015	0.007	0.034
Hearing Sensitivity	-0.006	0.036	0.049
Inductive Reasoning	0.028	0.053	-0.011
Information Ordering	0.007	0.028	-0.023
Installation	-0.007	0.026	-0.042
Instructing	0.016	0.017	0.025
Judgment and Decision Making	0.016	0.015	0.032

Table A1 (cont.): Factor Loadings of Importance Scores for O*NET Skills and Abilities

Learning Strategies	0.022	0.020	0.042
Management of Financial Resources	0.011	0.006	0.005
Management of Material Resources	0.010	0.031	-0.002
Management of Personnel Resources	0.020	0.026	0.025
Manual Dexterity	-0.044	0.033	-0.038
Mathematical Reasoning	0.024	0.030	-0.094
Mathematics	0.006	0.012	-0.032
Memorization	0.005	0.012	0.002
Monitoring	0.011	0.025	0.022
Multilimb Coordination	-0.021	0.005	0.039
Near Vision	0.002	0.025	-0.021
Negotiation	0.019	0.012	0.039
Night Vision	-0.010	0.023	0.050
Number Facility	0.013	0.031	-0.055
Operation Monitoring	-0.011	0.063	-0.051
Operation and Control	-0.020	0.028	-0.007
Operations Analysis	0.005	0.027	-0.074
Oral Comprehension	0.027	0.006	0.063
Oral Expression	0.034	0.011	0.085
Originality	0.023	0.039	0.011
Perceptual Speed	0.006	0.048	-0.009
Peripheral Vision	-0.024	0.051	0.093
Persuasion	0.016	0.005	0.048
Problem Sensitivity	0.007	0.020	0.022
Programming	0.003	-0.003	-0.024
Quality Control Analysis	0.000	0.035	-0.062
Rate Control	-0.019	-0.001	0.008
Reaction Time	-0.032	0.069	0.031
Reading Comprehension	0.026	0.021	-0.042
Repairing	-0.034	0.023	-0.020
Response Orientation	-0.019	0.042	0.062
Science	0.000	0.010	-0.035

Table A1 (cont.): Factor Loadings of Importance Scores for O*NET Skills and Abilities

Selective Attention	0.009	0.026	0.025
Service Orientation	0.010	0.006	0.034
Social Perceptiveness	0.034	0.005	0.099
Sound Localization	-0.018	0.030	0.034
Spatial Orientation	-0.011	0.027	0.056
Speaking	0.034	-0.008	0.077
Speech Clarity	0.019	0.013	0.057
Speech Recognition	0.021	0.020	0.051
Speed of Closure	0.008	0.045	0.017
Speed of Limb Movement	-0.016	0.013	0.024
Stamina	-0.014	0.024	0.092
Static Strength	-0.024	0.011	0.055
Systems Analysis	0.020	0.049	-0.032
Systems Evaluation	0.021	0.047	-0.025
Technology Design	0.000	0.027	-0.050
Time Management	0.016	0.014	0.023
Time Sharing	0.006	0.032	0.042
Troubleshooting	-0.009	0.068	-0.099
Trunk Strength	-0.016	0.002	0.015
Visual Color Discrimination	-0.003	0.020	-0.011
Visualization	-0.011	0.036	-0.026
Wrist-Finger Speed	-0.009	0.008	-0.019
Writing	0.025	0.014	-0.004
Written Comprehension	0.014	0.015	-0.021
Written Expression	0.027	0.004	0.000

Notes: Cell entries are estimates of the scores of predictions using the first, second, and third factors (in columns (1), (2), and (3), respectively). We first performed factor analysis on all 87 Skills and Abilities across all occupations in the O*Net dataset, as described in the text.

Table A2: Mapping between skills and abilities in O*NET and modified EQ and R-SQ questionnaires

Panel A		**Panel B**	
Skill/Ability	Score for EQ	*Skill/Ability*	Score for SQ
Social Perceptiveness	23	Information Ordering	19
Service Orientation	10	Flexibility of Closure	9
Persuasion	8	Inductive Reasoning	8
Active Listening	7	Memorization	8
Negotiation	5	Category Flexibility	7
Problem Sensitivity	4	Deductive Reasoning	7
Instructing	2	Installation	4
Speaking	1	Management of Financial Resources	4
		Spatial Orientation	4
		Visualization	4
		Mathematical Reasoning	3
		Number Facility	2
		Science	2
		Equipment Maintenance	1
		Equipment Selection	1
		Repairing	1
		Time Management	1
		Troubleshooting	1

Notes: The number associated to each skill and ability in the table above is the result of awarding one point every time the 5 co-authors thought that a person with a certain *skill* or *ability* as measured in O*NET would have answered with “agree” to the modified EQ and R-SQ questionnaires.

Table A3: Incidence of Child ASD by 2-Digit ISCO-88 Codes

A. Paternal Occupations

Occupation Code (ISCO-88 2-Digit)	Occupation Description	% with an ASD Child	% of Observations
81	Stationary-Plant and Related Operators	3.72	0.8
11	Legislators and Senior Officials	3.64	0.1
91	Sales and Services Elementary Occupations	3.59	4.2
82	Machine Operators and Assemblers	3.51	7.0
83	Drivers and Mobile-Plant Operators	3.49	3.9
31	Physical and Engineering Science Associate Professionals	3.37	5.8
93	Labourers in Mining, Construction, Manufacturing and Transport	3.33	2.6
21	Physical, Mathematical and Engineering Science Professionals	3.27	5.3
92	Agricultural, Fishery and Related Labourers	3.26	0.7
41	Office Clerks	3.23	7.2
72	Metal, Machinery and Related Trades Workers	3.06	10.6
73	Precision, Handicraft, Printing and Related Trades Workers	3.06	0.5
51	Personal and Protective Services Workers	3.03	6.9
74	Other Craft and Related Trades Workers	3.00	1.5
23	Teaching Professionals	2.80	3.8
71	Extraction and Building Trades Workers	2.80	8.3
33	Teaching Associate Professionals	2.78	2.0
13	General Managers	2.76	3.7
52	Models, Salespersons and Demonstrators	2.76	3.5
24	Other Professionals	2.50	4.1
22	Life Science and Health Professionals	2.48	0.9
32	Life Science and Health Associate Professionals	2.43	0.8
61	Market-Oriented Skilled Agricultural and Fishery Workers	2.42	2.5
34	Other Associate Professionals	2.31	9.5
42	Customer Services Clerks	2.18	1.1
12	Corporate Managers	2.16	2.7

Table A3: Incidence of Child ASD by 2-Digit ISCO-88 Codes (cont.)

B. Maternal Occupations

Occupation Code (ISCO-88 2-Digit)	Occupation Description	% with an ASD Child	% of Observations
83	Drivers and Mobile-Plant Operators	5.16	0.2
81	Stationary-Plant and Related Operators	5.11	0.1
93	Labourers in Mining, Construction, Manufacturing and Transport	5.08	0.2
72	Metal, Machinery and Related Trades Workers	3.83	0.3
71	Extraction and Building Trades Workers	3.82	0.7
74	Other Craft and Related Trades Workers	3.55	0.8
51	Personal and Protective Services Workers	3.45	20.8
91	Sales and Services Elementary Occupations	3.43	6.5
82	Machine Operators and Assemblers	3.36	4.2
73	Precision, Handicraft, Printing and Related Trades Workers	3.34	0.5
31	Physical and Engineering Science Associate Professionals	3.30	2.5
33	Teaching Associate Professionals	3.26	6.8
11	Legislators and Senior Officials	3.16	0.1
41	Office Clerks	3.06	16.5
21	Physical, Mathematical and Engineering Science Professionals	3.04	1.4
13	General Managers	3.00	1.4
52	Models, Salespersons and Demonstrators	2.89	5.5
23	Teaching Professionals	2.83	5.3
92	Agricultural, Fishery and Related Labourers	2.78	0.5
61	Market-Oriented Skilled Agricultural and Fishery Workers	2.77	0.7
24	Other Professionals	2.72	4.0
42	Customer Services Clerks	2.66	2.6
32	Life Science and Health Associate Professionals	2.55	6.1
22	Life Science and Health Professionals	2.43	1.8
34	Other Associate Professionals	2.29	9.9
12	Corporate Managers	2.23	0.9

Table A4: The Incidence of Child ASD by The Most Common Occupations by "Brain Type"

Fathers			Mothers		
Occupations	*Percentage of those in the Group who have Occupation*	*Percent w/ ASD Child*	*Occupations*	*Percentage of those in the Group who have Occupation*	*Percent w/ ASD Child*
Panel A: Balanced					
Carpenters and joiners	5.6%	2.6%	Nursing associates	11.1%	2.3%
Technical and commercial sales reps	5.1%	2.1%	Technical and commercial sales reps	3.1%	2.1%
Meat and fish processors	3.0%	3.5%	Secretaries	3.1%	2.5%
Farmers	2.8%	2.2%	Office clerks	3.0%	2.9%
Panel B: Empathizing					
Shop salespersons	9.8%	2.6%	Secretaries	13.0%	2.8%
Primary education teachers	5.9%	2.7%	Office clerks	10.2%	3.4%
Office clerks	5.4%	3.2%	Shop salespersons	9.6%	2.8%
Truck drivers	4.5%	3.6%	Primary education teachers	6.7%	2.8%
Panel C: Systemizing					
Auto mechanics	10.2%	2.8%	Medical doctors	11.2%	0.2%
Tool-makers	5.1%	2.8%	Life-science technicians	9.6%	2.9%
Agricultural or industrial machinery mechanics	4.2%	2.9%	Electronic-equipment assemblers	3.3%	3.5%
Machine-tool setters	3.6%	3.3%	Chemical and physical science techs	3.2%	3.2%
Panel D: Extremely Empathizing					
Custodians	15.7%	3.1%	Personal care workers (institution-based)	15.4%	3.8%
Child-care workers	12.2%	2.5%	Child-care workers	14.3%	3.5%
Personal care workers (institution-based)	11.4%	3.8%	Pre-school teaching associate	13.8%	3.3%
Pre-school teaching associate	10.8%	2.9%	Personal care workers (home based)	12.2%	4.1%

Table A4: The Incidence of Child ASD by The Most Common Occupations by "Brain Type" (cont'd)

Fathers			Mothers		
Occupations	*Percentage of those in the Group who have Occupation*	*Percent w/ ASD Child*	*Occupations*	*Percentage of those in the Group who have Occupation*	*Percent w/ ASD Child*
Panel E: Extremely Systemizing					
Electricians	11.0%	2.5%	Chemical and physical science techs	14.1%	3.2%
Computer assistants	6.6%	3.9%	Physical and engineering techs	8.9%	2.8%
Machine-tool setters	6.3%	3.1%	Draughtspersons	8.6%	2.7%
Agricultural or industrial machinery mechanics	6.2%	2.9.%	Architects and engineers	6.2%	2.8%