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Maternal age at first birth and offspring criminality: Using the children-of-twins design to test causal hypotheses

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Abstract

Teenage childbirth is a risk factor for poor offspring outcomes, particularly offspring antisocial behaviour. It is not clear if maternal age at first birth (MAFB) is causally associated with offspring antisocial behavior or if this association is due to selection factors that influence both the likelihood that a young woman gives birth early and that her offspring engage in antisocial behavior. The current study addresses the limitations of previous research by using longitudinal data from Swedish national registries and children-of-siblings and children-of-twins comparisons to identify the extent to which the association between MAFB and offspring criminal convictions is consistent with a causal influence and confounded by genetic or environmental factors that make cousins similar. We found offspring born to mothers who began childbearing earlier were more likely to be convicted of a crime than offspring born to mothers who delayed childbearing. The results from comparisons of differentially exposed cousins, especially born to discordant MZ twin sisters, provide support for a causal association between MAFB and offspring criminal convictions. The analyses also found little evidence for genetic confounding due to passive gene-environment correlation. Future studies are needed to replicate these findings and to identify environmental risk factors that mediate this causal association.

Keywords

Teenage childbirth; teenage motherhood; criminal behavior; antisocial behavior

Teenage childbearing is internationally recognized as a public health problem associated with a range of risks for both young mothers and their children (Alan Guttmacher Institute, 2010; Centers for Disease Control and Prevention, April 2011). Adolescence is a transitional period marked by social, psychological and biological changes, and childbearing during this period interferes with normative developmental processes. Teenage childbirth often disrupts young mothers' educational achievement and limits employment opportunities (Fergusson & Woodward, 1999), increasing their risk for substance abuse, mental health problems, and criminal convictions later in life (Coley & Chase-Lansdale, 1998). The offspring born to young mothers also experience poor developmental outcomes, including low birth weight, pre-term delivery, and behavioral and developmental problems (Chen et al., 2007; D'Onofrio et al., 2009). More broadly, teenage childbearing is associated with enormous

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economic costs for governments and health-care service-providers (Centers for Disease Control and Prevention, April 2011). In the United States, teenage childbirth is associated with \$6 billion in lost tax revenue and \$3 billion in public expenses per year (Hoffman, 2006). The poor economic, physical, and mental health outcomes for young mothers and their offspring, as well as the economic costs, make teenage childbearing an important target for public health prevention and intervention efforts.

While the rates of teenage childbirth in developed nations have declined dramatically since the 1990s, adverse consequences for teenage mothers and their children persist. In Sweden, public health initiatives to provide nation-wide comprehensive sex education, access to birth control and subsidized abortions have resulted in low rates of teenage pregnancy, abortions and childbirth (Danielsson, Rogala, & Sundstrom, 2001; Darroch, Singh, & Frost, 2001); compared to other developed nations, teenage childbirth is a particularly rare event (7 per 1,000 women 15–19 years old) (Singh & Darroch, 2000). Although the rates are low, there are still far-reaching negative consequences. Teenage mothers are at greater risk for premature death and socioeconomic disadvantage (Olausson, Haglund, & Weitoft, 2001; Olausson, Haglund, Weitoft, & Cnattingius, 2004) and their children are more likely to experience violent injuries during childhood (Ekeus, Christensen, & Hjern, 2004).

Policymakers seeking to make empirically supported decisions about the best targets for cost-effective public health interventions need research that can identify causal risk factors and the underlying mechanisms that account for these associations (Rutter et al., 2010). The majority of existing studies exploring the consequences of teenage childbirth have relied solely on longitudinal or cross-sectional, correlational studies. These studies have advanced our understanding of the risk correlates associated with teenage childbearing, but by virtue of their correlational nature, have not been able to identify causal associations between teenage childbirth and offspring outcomes (Coley & Chase-Lansdale, 1998; Coyne & D'Onofrio, in press).

Developmental theories: Explaining the association between maternal age and offspring antisocial behavior

Although previous research suggests that offspring born to teenage mothers are at higher risk for behavior problems and delinquency, (Jaffee, Caspi, Moffitt, Belsky, & Silva, 2001; Levine, Emery, & Pollack, 2007; Pogarsky, Lizotte, & Thornberry, 2003) the underlying mechanisms are poorly understood (Coley & Chase-Lansdale, 1998; Coyne & D'Onofrio, in press; Jaffee, et al., 2001; Jaffee, Strait, & Odgers, in press). In general, two main hypotheses are used to explain the processes that account for the higher rates of antisocial behavior among offspring of teenage mothers, the social influence hypothesis and the social selection hypothesis.

The social influence hypothesis posits that teenage childbirth is causally associated with poor offspring outcomes, including antisocial behavior, because early childbearing disrupts the developmental trajectory of young mothers, introducing social and economic stressors that constrain their ability to parent effectively (Jaffee, et al., 2001). This disruption puts teenage mothers on a trajectory of poverty, poor educational achievement, and ineffective parenting, which are environmental risk factors associated with offspring antisocial behavior (Coley & Chase-Lansdale, 1998). As a consequence of early childbearing, teen mothers have lower educational achievement and constrained employment opportunities (Coley & Chase-Lansdale, 1998). Additionally, teen mothers are more likely to be single parents (Coley & Chase-Lansdale, 1998). The combination of these factors and other related constructs increases the likelihood that teenage mothers will raise their children in disadvantaged circumstances, marked by poverty and low maternal education attainment,

which are subsequently associated with poor outcomes. The social-influence hypothesis, thus, posits that the developmentally disruptive effect of the timing of teenage childbirth specifically causes poor outcomes for teenage mothers and their children.

In contrast, the social selection hypothesis asserts there are biopsychosocial factors that both (a) place certain women at higher risk for teen childbirth and (b) influence the development of the offspring (Coley & Chase-Lansdale, 1998; Jaffee, et al., 2001). These factors could account for the association between teenage childbirth and offspring antisocial behavior. Previous studies suggest that teenage mothers tend to come from more disadvantaged backgrounds than mothers who delay childbirth (Coley & Chase-Lansdale, 1998). On average, young women who become teenage mothers are raised by single parents with low educational attainment in communities with high rates of poverty and crime (Coley & Chase-Lansdale, 1998). Prior to pregnancy, these young women come from more impoverished homes, have poorer academic achievement before childbirth, and are more delinquent than their peers who delay childbirth (Coley & Chase-Lansdale, 1998; Pogarsky, Thornberry, & Lizotte, 2006; Woodward & Fergusson, 1999). These environmental risk factors are also independently associated with poor outcomes for offspring, including antisocial behavior (Lahey, Moffitt, & Caspi, 2003; Nagin, Pogarsky, & Farrington, 1997; Pogarsky, et al., 2003; Pogarsky, et al., 2006). Offspring raised by mothers with poor education attainment, from high poverty communities may be at increased risk for poor outcome regardless of how old their mothers were at childbirth. Offspring antisocial behavior, therefore, could be due to environmental selection factors that influence both the likelihood that a young woman becomes a teen mother and the likelihood that her children experience poor outcomes.

The selection factors accounting for the statistical association between maternal age at birth and offspring antisocial behavior could be environmental and/or genetic. The possibility of genetic selection factors stems from a phenomenon referred to as gene-environment correlation (e.g., Scarr & McCartney, 1983). Gene-environment correlation occurs when environmental risks (in this case maternal teenage childbirth) are correlated with genetic risks. There is evidence from behavior genetics studies that age at first childbearing is heritable (Rodgers, Bard, & Miller, 2007), which brings about the possibility that genetic factors passed down from parents to their offspring (due to passive gene-environment correlation) account for the poor developmental outcomes associated with teenage childbearing (Rutter, 2007). Studies, therefore, must account for the possibility that shared genetic liability (the same genetic factors influencing maternal teenage childbirth and offspring development due to passive gene-environment correlation) account for associations between teenage childbirth and offspring antisocial behavior (Lahey & D'Onofrio, 2010). It is important to note that the presence of passive gene-environment correlation does not necessitate that shared genetic liability among parents and offspring account for the associations between teenage childbirth and offspring development (Rutter, Silberg, & Simonoff, 1993). The presence of passive gene-environment, however, raises the possibility that genetic factors could confound the association.

Testing social influence versus social selection

Most previous studies exploring the consequences of teenage childbirth have relied on research approaches that do not include design features that can rigorously test the competing hypotheses (Coley & Chase-Lansdale, 1998; Coyne & D'Onofrio, in press). The existing studies have generally relied on using statistical methods (e.g., adding measured covariates in analytical models) to help control for selection factors. But, the reliance on those methods can provide misleading results because of the inability of studies to include reliable and valid measures of all salient confounding factors (e.g., Rutter, Pickles, Murray,

& Eaves, 2001). Again, the associations that have been identified may be due to genetic or environmental confounds that influence both the likelihood of teenage childbirth and offspring's outcomes (and confounds that were not measured in the study or were not measured accurately).

Randomized experiments are the gold-standard for testing causal hypotheses, however, ethical and practical constraints prevent the use of randomized experiments for testing associations between teenage childbirth and offspring outcomes (West, 2009). Quasi-experimental designs provide methods for testing causal hypotheses and ruling out alternative hypotheses that do not rely simply on statistical controls (Rutter, et al., 2001; Shadish, Cook, & Campbell, 2002). In particular, family-based quasi-experimental designs (e.g., sibling and cousin discordance studies) have been used to explore the association between maternal age at childbirth and offspring antisocial behavior (Coyne & D'Onofrio, in press; Jaffee, et al., in press).

Several quasi-experimental studies have attempted to differentiate between the specific effects of maternal age at childbearing and the influence of family background characteristics by using sibling – and cousin-comparison analyses. Geronimus et al. (1994) conducted a landmark study using a nationally representative sample to compare children born to teenage mothers with their later-born cousins. Cousin-comparisons contrast differentially exposed offspring of sisters discordant for teenage childbirth (i.e., children born to teenage mothers are compared to their cousins who were born to older mothers). These comparisons control for unmeasured, genetic (cousins share on average 12.5% of their genetic makeup) and environmental factors that make cousins similar (D'Onofrio et al., 2005). The study found no differences in achievement scores between children born to teenage mothers and those born to older mothers, and in some cases, children born to teenage mothers performed better (Geronimus, Korenman, & Hillemeier, 1994). The study suggested that the differences in offspring achievement were not caused by being born to young mothers; rather, the results suggest that unmeasured factors that make cousins similar account for the increased risk of achievement problems observed among offspring born to teenage mothers. Similarly, Turley (2003) used cousin comparisons to test whether there was a causal association between teenage childbirth and offspring scores on standardized tests of achievement and behavior problems. The cousins had similar achievement scores and behavior problems, regardless of their mothers' age at childbirth. The study also suggested that maternal age at birth is not causally associated with poor offspring achievement scores and behavior problems; instead, differences in family background factors accounted for increased risk among children born to teen mothers compared to children born to older mothers.

In contrast, a few quasi-experimental studies have found support for a causal association between maternal age at childbirth and offspring antisocial behavior. A study using sibling comparisons found that maternal age was independently associated with offspring childhood behavior problems (D'Onofrio et al., 2009), which supports a causal association. The discordant-sibling design compared outcomes for earlier and later-born offspring, which controls for unmeasured environmental and genetic factors that are shared by siblings in a nuclear family, in order to test causal hypotheses about environmental effects of teenage childbearing (Lahey & D'Onofrio, 2010). The study also found the association was moderated by birth order—the association between maternal age at childbirth and childhood behavior problems was stronger for second and third-born offspring (D'Onofrio, et al., 2009).

Harden and colleagues (2007) also found support for a causal association between maternal age and adolescent offspring outcomes using a children of twins design (Harden et al.,

2007). In the children-of-twins design differentially exposed offspring of dizygotic (DZ) and monozygotic (MZ) twins are compared to each other. Contrasting the offspring of DZ and MZ twins provides information about possible genetic factors that confound the association between adolescent childbirth and offspring criminal convictions (D'Onofrio et al., 2003; D'Onofrio et al., 2005; Heath, Kendler, Eaves, & Markell, 1985). Harden et al. (2007) found the association between teenage childbirth and offspring behavior and substance use problems remained even when controlling for genetic factors passed down from the twins to their offspring and environmental factors shared by cousins.

More recently, findings from a sibling comparison study using data from the Swedish national registries that are analyzed in the current manuscript indicated that maternal focal age at each childbirth was not independently associated with offspring criminal convictions when comparing differentially exposed siblings (Coyne, Långström, Lichtenstein, & D'Onofrio, submitted for review). The findings suggest that the causal mechanism linking early maternal age at childbirth and offspring criminality is shared by siblings, and not specific to each child.

Current Status of Quasi-Experimental Studies of Early Maternal Age at Childbirth

The existing quasi-experimental studies of the association between maternal age at childbirth and offspring development are conflicting (Coyne & D'Onofrio, in press; Jaffee, et al., in press). Given the implications of such studies for public policy (Rutter, et al., 2010) how do we proceed and more fully explicate the mechanisms responsible for the associations? Research must carefully articulate the hypothesized mechanisms and carefully consider two critical factors: (1) the assumptions inherent in each quasi-experimental design and (2) the specific sample being used.

First, the sibling comparison approach may not be the most appropriate design for studying the consequences of early maternal age at childbirth. For example, our recent sibling-comparison study (Coyne, Långström, Lichtenstein, & D'Onofrio, submitted for review) found no association between the mother's specific age at childbirth and offspring criminal convictions when comparing siblings differentially exposed to teenage childbirth; rather, familial factors or risks (genetic and/or early environmental) shared by all children of a teenage mother accounted for the association. This could be interpreted as being inconsistent with the social influence hypothesis because familial background factors were responsible. Alternatively, the increased risk of criminal convictions for early- and later-born siblings may reflect the cumulative effect of changes of having a first child at an early age--the subsequent changes in family structure, diminished financial and social resources in families in which the mother had her first child at an early age may influence all offspring of the mother (Nagin, et al., 1997; Pogarsky, et al., 2006). It is important to note that sibling-comparisons cannot account for the extent to which one sibling's exposure to a risk factor may influence other siblings in the family, nor study examine the causal mechanisms associated with environmental factors that are shared by all siblings in a family (Donovan & Susser, 2011; Lahey & D'Onofrio, 2010). Therefore, maternal age at the birth of each child may not be as important as maternal age at her first birth. In fact, researchers have posited that maternal age at first birth (MAFB) predicts offspring antisocial outcomes better than age at birth for the focal child (Geronimus, et al., 1994; Jaffee, et al., 2001; Nagin, et al., 1997; Pogarsky, et al., 2003; Turley, 2003).

Second, it is important to utilize samples with adequate variability and include enough offspring born to young women to adequately estimate small to medium associations with offspring development. Both Turley (2003) and Geronimus and colleagues (1994) both

found that poor outcomes in childhood were not due to MAFB while using cousin comparisons. It is important to note, however, that both of the studies included a restricted range of MAFB. The studies, as a consequence, may not have had the sample size to precisely estimate the associations. In fact, a cousin and sibling-comparison study of maternal age at childbirth was conducted on the same sample as Geronimus et al. (1994) and Turley (2003) studies after more women in the original study had children. The study found an independent association between early maternal age at childbirth and offspring antisocial behavior (D'Onofrio, et al., 2009). A restricted range of MAFB may have limited the generalizability of some of the existing cousin-comparison studies.

The current study sought to address the limitations of previous studies of early maternal age at childbirth. We used longitudinal data from Swedish national registries to identify cousins (both children-of-siblings and children-of-twins) to (1) test the extent to which MAFB is causally associated with offspring criminal convictions and (2) determine the extent to which the statistical association between MAFB and offspring criminal convictions was confounded by genetic confounds (due to passive rGE) and environmental factors that make cousins similar. To more fully understand the mechanisms through which early maternal age at first childbirth influences offspring antisocial behavior we used children-of-siblings and children-of-twins designs, that is, designs which can explore a risk factor shared by all siblings in a family (here MAFB). The current study is the first, to our knowledge, to use a large, population-based sample with great variability in MAFB, to test these associations using such designs.

Children-of-Siblings and Children-of-Twins Designs

Children-of-siblings and children-of-twins designs are genetically informative, quasi-experimental methods to study the association between environmental risk factors shared by all siblings in a nuclear family and offspring outcomes. Rather than comparing unrelated offspring in a population who are differentially exposed to early MAFB (e.g., offspring born to a mother who first gave birth as a teenager compared to an offspring born to an unrelated mother who first gave birth as an adult) these designs compare differentially exposed cousins. In this way, the unexposed cousin serves as a control for environmental and genetic factors shared by offspring in an extended family (D'Onofrio, 2005; D'Onofrio et al., 2007). In the children-of-siblings design, the offspring of full sisters are compared. These full cousins share 12.5% of their genetic makeup but their mothers began childbirth at different ages. The children-of-twins design is similar: offspring born to discordant dizygotic (DZ) and monozygotic (MZ) twins sisters are compared to each other. The cousins born to DZ twin sisters, who are similar to cousins born to full sisters, share 12.5% of their genetic makeup. The offspring born to MZ twins, though, share 25% of their genetic makeup--socially they are cousins but genetically they are half-siblings. Contrasting the offspring of DZ and MZ twins provides information about possible genetic and environmental factors that confound the association between early maternal age at first birth and offspring criminal convictions (D'Onofrio, et al., 2003; D'Onofrio, et al., 2005; Eaves, Silberg, & Maes, 2005; Heath, et al., 1985).

The primary advantage of the children-of-siblings and children-of-twins designs is the ability to more specifically identify the environmental and genetic mechanisms that account for statistical associations between early maternal age at first birth and offspring criminal convictions. First, these designs can identify the degree to which the association between early maternal age at first birth and offspring risk of criminal conviction is consistent with a causal influence (supporting the social influence hypothesis) or is due to selection factors (supporting the social selection hypothesis). The strongest test of the theories comes from the comparison of offspring of MZ twins, because the design accounts for genetic and

environmental factors that make the adult twins similar. Second, if selection factors are important the children-of-siblings/twins design can differentiate between the environmental and genetic selection factors. Combining comparisons of differentially exposed offspring from multiple relative groups (e.g., full sisters, DZ and MZ twin sisters), thus, lets researchers measure the extent to which the confounds are due to environmental or genetic selection factors.

Inferences about the putative causal association between early maternal age at first childbirth and offspring criminal convictions are based on the pattern of results from the children-of-siblings and children-of-twins designs. Figure 1 includes the expected patterns of results for different types of association between the risk factor (e.g., teenage first birth) and offspring outcome (e.g., criminal conviction). The results in Figure 1 are from hypothetical analyses comparing women who had their first child as a teenager (15–19 years old at first birth) and women who had their first child as an adult (20 years old or older at first birth). The hazard ratios represent the risk for offspring that have been exposed to maternal teenage first birth using different comparison groups. In pattern A, the results are consistent with a causal association (supporting the social influence hypothesis) because the association between MAFB and offspring risk of criminal conviction persists in every comparison group. Most importantly, the association remains controlling for genetic and environmental factors shared by offspring born to MZ twins. In pattern B, the results suggest the statistical association between MAFB and offspring criminal conviction may be accounted for by genetic confounds. The social selection hypothesis would be supported because MAFB is not associated with offspring criminal convictions among offspring of MZ twins. The results suggest the confounding factors are genetic because the magnitude of the association is smaller in cousin comparisons that control for more genetic risk (i.e., the association is somewhat reduced when comparing full cousins and offspring of DZ twins and the association is further reduced when comparing the offspring of MZ twins). The results in pattern C suggest that environmental confounds account for the association between MAFB and offspring criminal convictions. Again, the selection hypothesis would be supported because MAFB was not associated with offspring criminality among offspring of MZ twins. The confounding factors would be environmental because the magnitude of the association is reduced in all the cousin comparisons, regardless of degree of genetic relatedness.

The children-of-siblings and children-of-twins designs can help account for confounding factors, but the approaches cannot rule out all confounding factors. In particular, the design cannot account for environmental factors that make the adult twins dissimilar (e.g., environmental factors that influence one twin but not the other twin) (D'Onofrio, et al., 2003; Rutter et al., 2001). The design also cannot account for genetic factors passed down from the spouses/partners of the twins (in this case, the fathers) (Eaves, et al., 2005). To help address these limitations, the current study combines the quasi-experimental designs with the inclusion of statistical covariates to help account for additional confounding factors.

Methods

Sample

We merged longitudinal population registries maintained by government and research agencies in Sweden. The Multi-Generation Register (MGR) (Statistics Sweden, 2006), kept by Statistics Sweden, contains each individual's unique identifier and allows researchers to link all children to their biological mothers and fathers (based on maternal reports) and identify all siblings and offspring of siblings (cousins). All siblings in the current study were full siblings. The database also includes the date of birth for all individuals. The National Crime Register (NCR) (Fazel & Grann, 2006) includes information about all criminal

convictions of those aged 15 (the age of criminal responsibility) and older since 1960. The register provides detailed information about the timing, nature and number of all offenses that led to court convictions. The Education Register (ER) (Sweden, 2004) contains information on the highest level of completed formal education. The Migration Register (MR) provides information on individuals who immigrated to or emigrated from Sweden. The Cause of Death Register, maintained by the National Board of Health and Welfare, includes information on causes of death for all individuals since 1958. Immigration and death information were used to identify individuals who emigrated or died before they were 15 years old. The Swedish Twin Register (STR) contains basic information on all twins born in Sweden since 1886 and was used to identify dizygotic (DZ) and monozygotic (MZ) twin sisters born 1955–1970 (Lichtenstein et al., 2006).

Inclusion and exclusion criteria

A sample of women born between 1955 and 1970 ($n=1,139,392$) was selected from the MGR (see Figure 2). Women missing parental identification information ($n=253,374$), who died ($n=3,588$) or emigrated ($N=38,196$) before age 20 were dropped. Women who never gave birth ($n=135,799$) and women who gave birth before age 13 ($n=2$) also were excluded. In Sweden, the age of criminal responsibility is 15. Therefore offspring under the age of 15 ($n=511,599$) and children who died ($n=6,445$) or emigrated ($n=22,783$) before age 15 were not eligible for inclusion in analyses for the chosen criminal outcomes. The final sample includes 1,084,939 offspring born to 535,779 different mothers and 621,301 different fathers. The subsample of sister pairs created for the full cousin comparisons included only the two oldest sisters in each family and all of their children. Due to the small number of half cousins identified in the Swedish registries during this cohort, half cousins were excluded from the analyses. The sister subsample included 79,545 sister pairs with 337,880 offspring; 14,896 sister pairs were discordant for teenage childbirth (i.e., one sister gave birth as a teenager and the other gave birth as an adult). The twin offspring subsample included DZ twin sisters ($n=1,840$) and MZ twin sisters ($n=1,512$) and their offspring ($n=7,042$). There were 286 DZ twin pairs discordant for teenage first birth and 168 MZ twin pairs discordant for teenage childbirth.

Measures

Maternal age at first childbirth—The Multi-Generation Register includes information about maternal age at first birth (MAFB) and the birth order of each live-born child. We measured MAFB as an ordinal, binary, and linear variable and ran the same models with each form of MAFB as a predictor. To test nonlinear associations we constructed binary and ordinal versions of MAFB. The binary variable categorized MAFB as *teenage first birth* if the age at first birth was between 13–19 years old and *adult first birth* if the age at first birth was at least 20 years old. The average rate of teenage childbirth in this sample between 1955 and 1970 was 9.8% of all first live births, consistent with other reports (Danielsson, et al., 2001; Darroch, et al., 2001). The ordinal variable decomposed MAFB into four categories: first birth between 13–15 years old, 16–18 years old, 19–23 years old, and 24 years or older (the reference group). The linear variable re-centered MAFB at 24, the mean age of first birth in the full sample. For women who began childbearing before age 24, MAFB was calculated as a value less than zero and for women who began childbearing after 24 MAFB was calculated as a value greater than zero.

Measured offspring covariates—Demographic characteristics of the sample are presented in Table 1. Offspring gender, birth order and paternal age at birth were included as offspring-specific covariates in all analytic models. The fathers of offspring born to teenage mothers are on average younger (26.8 years old) than the fathers of offspring born to adult mothers (30.1 years old).

Measured parental covariates—Maternal and paternal history of criminal conviction and highest level of education were included as risk covariates. Demographic characteristics of the parents are presented in Table 1. Maternal and paternal educational attainment was indexed as low if their highest level of education was less than 9 years of compulsory primary and lower secondary education. In Sweden, grades 1–9 are compulsory and equivalent to elementary and middle school in the United States and many other developed countries. Dummy codes were created to compare (a) low educational attainment and (b) those with missing values to the high educational attainment group. A greater proportion of mothers who began childbearing as teenagers (1.2%) and the fathers of their offspring (7.6%) had low educational attainment as compared to the proportion of mothers who began childbearing as adults (0.2%) and the fathers of their offspring (2.7%). Maternal and paternal history of criminal conviction was based on record of any criminal offense in the National Crime Register through 2004. Similar to the pattern observed with educational attainment, a greater proportion of mothers who began childbearing as teenagers (21.4%) and the fathers of their children (60.8%) had a criminal conviction history as compared to the mothers who began childbearing as adults (11.5%) and the fathers of their children (42.6%).

Offspring criminal outcomes—Offspring history of any criminal conviction was used as the primary outcome for analyses. Sensitivity analyses were conducted on four types of offspring criminal convictions as outcomes in the current study: First, violent crimes defined according to the Swedish Penal Code (SPC) as attempted or completed murder, manslaughter, or filicide, assault, kidnapping, illegal restraint, illegal coercion or threats, robbery, threats or violence against an officer, arson, gross violation of a person's (or woman's) integrity, or harassment. Any sexual offense was also included [rape, sexual coercion, child molestation, and sexual harassment including indecent exposure]. Aggravated forms of included offences were included wherever applicable. This corresponds to a definition of violent offending used in earlier scientific reports from Sweden (Fazel, Långström, Hjern, Grann, & Lichtenstein, 2009; Långström, Grann, Ruchkin, Sjöstedt, & Fazel, 2008). Second, driving-related crimes committed while under the influence of alcohol or other substance. Third, narcotic drug offenses as defined by the Narcotic Drugs Criminal Act, which includes possession for personal use, supply and manufacture, and consumption. Fourth, nonviolent crimes defined as all other crimes not related to violent or drug-related offenses.

Analyses were based on first conviction for each of these types of crime (starting from age 15, the age of criminal responsibility). The time-to-event for these outcomes is based on the date of the first criminal act leading to a criminal conviction. In the current sample, Kaplan-Meier estimates indicated that by 25 years old, 16% (n=134,160) of the sample had at least one criminal conviction, 4% (n=31,751) had at least one violent criminal conviction, 6% (n=49,151) had at least one nonviolent criminal conviction and 2% (n=16,181) had at least one driving-related conviction, 5% (n=19,506) had at least one drug-related conviction.

Statistical analyses

Preliminary analyses

We conducted preliminary analyses to determine whether the association between MAFB and offspring criminal convictions was best modeled as a linear or nonlinear relationship. We compared the association between MAFB and offspring criminality using different distributions of MAFB: (1) MAFB measured as an ordinal variable (2) MAFB considered a linear predictor and (3) MAFB as a linear and quadratic predictor.

First, we were interested in whether younger teenage first birth (13–15 years old), later teenage first birth (16–18 years old) or first birth during early adulthood (19–23 years old) were related to higher risk of criminal conviction than first birth during adulthood (24 years old and older). We fit Cox regression models testing the unadjusted nonlinear association between MAFB as an ordinal variable and offspring history of any criminal conviction. Second, we fit Cox regression models testing the unadjusted linear association between MAFB as a linear variable and offspring history of any criminal conviction. Third, we compared analyses using linear and quadratic models of association to examine whether the linear measurement of MAFB was a close approximation of both the ordinal and quadratic results. These analyses provided justification that using a linear model provided a good approximation of the association.

Primary analyses: Quasi-Experimental Analyses

Association between MAFB (linear) and offspring criminal convictions—

Analyses with the linear measure of MAFB were used to identify the (1) extent to which the association between MAFB and offspring criminal convictions was consistent with a causal influence and (2) determine the extent to which any confounding factors were due to shared genetic liability between the mothers and their offspring (passive gene-environment correlation). Cox regression analyses were used to deal with the right-censored outcome measures (i.e., not all of the offspring in the sample had lived through the risk period for criminal convictions). All models statistically controlled for offspring gender, birth order, and father's age at birth. The analyses used robust standard errors to account for the nested nature of the data (i.e., sisters and cousins were nested within extended families).

Six Cox regression models were fit to offspring history of any criminal conviction as an outcome. Model 1 tested the unadjusted association between MAFB and any criminal conviction. This model provided an unadjusted estimate of the association between MAFB and offspring criminal convictions in the entire population of offspring. Model 2 estimated the same associations while including measured parental covariates. This analysis provided an estimate of the association between MAFB and offspring criminal convictions that is statistically independent of the measured parental covariates, the typical manner in which studies have tried to account for selection factors.

Model 3, in contrast, fit a fixed-effects model to test the association between MAFB and offspring criminal conviction in the subsample of full sister-pairs to hold constant all factors shared by full cousins. The third model compared differentially exposed full cousins (offspring born to maternal full siblings who began childbearing at different ages). These analyses estimated association between MAFB and offspring criminal conviction while controlling for unmeasured, family-level genetic and environmental factors that make cousins similar (D'Onofrio, et al., 2005; Heath, et al., 1985; Silberg & Eaves, 2004). Model 4 and Model 5 compared the children-of-twins. Model 4 fit a fixed-effects model comparing the criminal conviction history of offspring of dizygotic (DZ) twin sisters discordant for age at first birth. Offspring born to DZ twin sisters are genetically equivalent to full cousins and share 12.5% of their genetic makeup. The results of these analyses provide a within-twin-family estimate of the association between MAFB and offspring criminal conviction, while controlling for genetic and environmental factors that make cousins born to DZ twin sisters similar. Model 5 fit a fixed-effects model comparing offspring of monozygotic (MZ) twin sisters discordant for age at first birth. Because children born to MZ twins are genetically equivalent to half-siblings, sharing 25% of their genes, the results of these analyses provide a within-twin-family estimate that controls for more genetic factors. Finally, Model 6 fit a fixed-effects model in MZ twin families while also including the measured parental covariates to control for the nuclear family-level confounds that are not controlled for in the children-of-twins design. We included the parental covariates to account for possible

confounding variables (e.g., offspring's father's criminal history) that differed between twins and were not controlled for in the children-of-twins design (Eaves, et al., 2005).

Again, using multiple groups of relatives who differ in their relatedness and their exposure to the risk factor (teenage childbirth) allowed us to measure whether shared genetic background factors moderate the statistical association between early childbearing and offspring outcomes (Heath, et al., 1985; Silberg & Eaves, 2004). Contrasting the offspring of full sisters, DZ, and MZ twins provides information about (1) the putative causal association between teenage childbearing and criminal conviction and (2) the extent to which any confounding factors are due to shared genetic liability (passive gene-environment correlation). For example, if the association between MAFB and offspring criminal convictions is stronger when comparing offspring of DZ twins (or full sisters) than the strength of the association when comparing offspring of MZ twins then the results suggest that genetic factors are confounding the association between MAFB and offspring criminal convictions because the comparison of offspring of MZ twins controls for more genetic confounding than the comparison of the offspring of DZ twins (D'Onofrio et al., 2005). In contrast, if the statistical association between teenage childbearing and offspring criminal conviction is reduced across all relative groups (offspring of full, DZ and MZ sisters) as compared to unrelated offspring, the pattern of results would support confounding due to environmental factors shared by adult siblings. If the association between MAFB and criminal outcomes remains significant when comparing offspring of MZ twin sisters the results would support a causal association. Including a model that compares MZ twin sisters and the parental covariates (Model 6) provides the most rigorous test of whether the associations between MAFB and offspring outcomes are causal or accounted for by between family differences in family background factors.

In subsequent analyses we specifically tested whether the within extended-family estimate was moderated by zygosity in the children-of-twins models for each offspring outcome, which provides a statistical examination of the role of passive gene-environment correlation. A model for each outcome measure explored whether the within-family estimate (comparison of the offspring of discordant twins) is different for offspring of DZ and MZ sisters. These models included a variable for the mean MAFB for each twin pair (to estimate between-twin pair differences), a variable for the deviation score for each co-twin sister (to estimate within-twin pair differences), and an interaction between the MAFB deviation variable parameter and zygosity (coded: 0=MZ, 1=DZ). The interaction term provided statistical information about the difference between the MAFB parameter estimates from the fixed-effect models (Model 4 and Model 5) to examine whether the within twin-family estimate was larger for the offspring of DZ twins than the offspring of MZ twins. For further details concerning these models see D'Onofrio et al. (2005).

Association between teenage childbirth (binary) and offspring criminal convictions—Most studies focus on the distinction between teenage and adult childbearing. Because we wanted to provide results that can be compared with the existing literature, we also conducted the quasi-experimental analyses using the binary measure of MAFB (first birth as a teenage versus first birth as an adult). The same six Cox regression models were used to test the association between MAFB and offspring criminal convictions.

Sensitivity analyses

Sensitivity analyses using transformations of the MAFB variable (e.g., linear and binary) were conducted to check whether the association between MAFB and specific types of criminal conviction outcomes (e.g., violent, driving-related, etc.) replicated the findings for the general criminal conviction outcome in the primary analyses.

First, analyses were conducted using the linear measurement of MAFB as a predictor and the other offspring criminal outcomes (violent, nonviolent, driving- and drug-related convictions). The same six Cox regression models were fit to these outcomes as were fit to the any criminal conviction outcome. Second, we conducted sensitivity analyses using the binary measure of MAFB as a predictor using the other criminal outcomes (i.e., we ran the models predicting violent, nonviolent, driving- and drug-related convictions). Again, the same six Cox regression models were fit to these outcomes as were fit to the any criminal conviction outcome.

Results

Preliminary analyses

The analyses first compared the ordinal approach of measuring MAFB to a linear, continuous model. The full pattern of results from the ordinal analyses and linear model can be seen in Figure 3). The analyses comparing the linear and quadratic models of association between MAFB and offspring convictions can be found in Appendix Figure 1. The comparisons suggested a linear model would fit the data well. For example, in both the linear and ordinal models, offspring risk of criminal conviction decreases as maternal age at first birth increases. We, therefore, conducted the quasi-experimental analyses considering two distributions. First, we used a linear measure of MAFB because of the increased statistical power of considering MAFB continuously. Second, we used a binary measure of MAFB (comparing teenage childbirth to adult childbirth) because of the heavy emphasis in the literature on specifically examining teenage childbirth.

Primary analyses

Association between MAFB (linear) and offspring criminal convictions—For all analyses, the Hazard Ratios with corresponding 95% CIs for MAFB are shown in Figure 4 (Panel A) and results are shown in Table 2. MAFB was highly associated with any offspring criminal conviction. Model 1 indicated that for every one year increase in MAFB offspring odds of any criminal conviction was reduced by 8% ($b=-0.09$; $HR=0.92$; $p<.0001$)—a hazard ratio below 1.00 represents a decrease in the odds of offspring criminal conviction. In Model 2 the parameter associated with MAFB was slightly attenuated ($b=-0.07$; $HR=0.94$; $p<.0001$), but remained a strong predictor of offspring criminal convictions after the inclusion of the parental covariates. Similarly, when comparing differentially exposed full cousins using a fixed-effects model the MAFB parameter was reduced further ($b=-0.05$; $HR=0.95$, $p<.0001$), but MAFB remained a significant predictor of any offspring criminal conviction. For every year a mother delayed childbearing, her offspring's risk of criminal conviction decreased by 5% in comparison to their cousins born to her sister who began childbearing earlier. Model 4 compared cousins born to DZ twin sisters using a fixed effect model, and the effect of MAFB remained significant ($b=-0.10$; $HR: 0.91$, $p<.0001$). Model 5 compared cousins born to MZ twins, who are genetically equivalent as half-siblings, and MAFB still independently predicted offspring criminal convictions ($b=-0.10$; $HR: 0.90$, $p<.0001$). Further analyses using a deviation score for each co-twin sister's age at first birth (to estimate within-twin pair differences) and testing zygosity as a moderator found no difference in the estimates for Model 4 and Model 5. In these analyses, the within-twin-pair effect of MAFB did not differ by zygosity ($b=-0.01$ logits, $SE=0.03$) indicating that the attenuation of MAFB in comparison of differentially exposed children of MZ twins does not appear to be due to genetic confounds (Table 4). Model 6 also compared offspring of MZ twin sisters but included parental covariates to account for potential within-twin-family confounds. Including the covariates slightly attenuated the magnitude of the association but MAFB was still a robust, independent predictor of offspring criminal conviction ($b=-0.09$; $HR: 0.92$, $p<.0001$). The analyses suggest that when statistically controlling for measured

covariates and using a quasi-experimental design to rule out genetic factors passed down from mothers to their offspring and environmental factors that make cousins similar, MAFB was still strongly associated with offspring criminal convictions.

Association between teenage childbirth (binary) and offspring criminal convictions—For all analyses, results are shown in Table 3 and the Hazard Ratios associated with teenage childbirth are presented in Figure 3 (Panel B). Model 1 indicated that teenage first birth increased the odds of any criminal conviction by a factor of 1.64 ($b=0.49$; $HR=1.64$; $p<.0001$). In Model 2 the parameter associated with teenage MAFB was somewhat attenuated ($b=0.36$; $HR=1.44$; $p<.0001$), but teenage childbirth remained a strong predictor of offspring criminal convictions after the inclusion of the parental covariates. Similarly, when comparing differentially exposed full cousins using a fixed effects model the teenage childbirth parameter was slightly reduced ($b=0.29$; $HR=1.33$, $p<.0001$), but teenage MAFB remained a significant predictor of any offspring criminal conviction. Model 4 compared cousins born to DZ twin sisters using a fixed effect model, and the effect of teenage MAFB remained large and statistically significant ($b=0.67$; $HR: 1.96$, $p<.0001$). Model 5 compared cousins born to MZ twins, and teenage MAFB still independently predicted offspring criminal convictions ($b=0.44$; $HR: 1.56$, $p<.0001$). Model 6 also compared offspring of MZ twin sisters but included parental covariates to account for potential within-twin-family confounds. Including the covariates slightly attenuated the magnitude of the association, but MAFB was still a robust predictor of offspring criminal conviction ($b=0.34$; $HR: 1.40$, $p<.0001$). Offspring born to a teenage mother were 1.4 times more likely to be convicted of any crime than their cousins born to their mother's MZ co-twin who delayed childbearing until adulthood (while also controlling for statistical covariates). Further analyses using a deviation score for each co-twin sister's age at first birth (to estimate within-twin pair differences) and testing zygosity as a moderator found no difference in the estimates for Model 4 and Model 5. In these analyses, the within-twin-pair effect of MAFB did not differ by zygosity ($b=0.21$ logits, $SE=0.28$) indicating that the attenuation of MAFB in comparison of differentially exposed children of MZ twins does not appear to be due to genetic confounds (Table 5).

The pattern of results seen in Figure 3 (Panel B) is very similar to the pattern of hypothetical results seen in Figure 2 (Pattern A). Although there is more variability in the hazard ratios seen in Figure 3 the general pattern of results from comparisons of differentially exposed cousins, offspring of DZ twins and offspring of MZ twins is consistent with the causal association posited by the social influence hypothesis.

Sensitivity analyses

First, we conducted sensitivity using the linear measure of MAFB as a predictor with different criminal outcomes. We used the same six Cox regression models to test the association between MAFB and other criminal convictions (violent, nonviolent, driving- and drug-related convictions). The pattern of results for these criminal outcomes was similar to the pattern of results seen for any criminal conviction (data not shown, results available upon request). For each of these outcomes, the association remains robust in the final models comparing differentially exposed offspring of MZ twins and including parental covariates. The magnitude of the association between MAFB and these offspring outcomes remains large despite the increase in standard errors (as the prevalence of some of the types of criminal convictions is low).

Second, we conducted sensitivity analyses using the binary measure of MAFB (teenage childbirth) as a predictor of the other criminal outcomes. Again, the pattern of results for these criminal outcomes was similar to the pattern of results seen for any criminal

conviction (data not shown, results available upon request). For each of these outcomes, the association remains robust in the final models comparing differentially exposed offspring of MZ twins and including parental covariates. The magnitude of the association between MAFB and these offspring outcomes remains large despite the increase in standard errors.

Discussion

To our knowledge, this is the first study to test whether maternal age at first birth is associated with offspring criminal outcomes using children of siblings and children-of-twins comparisons to account for genetic and environmental factors shared among offspring born in an extended family. The current study was able to account for unmeasured genetic confounds that are shared among offspring born to MZ twins and environmental confounds that make siblings similar. Additionally, the current study exploits different degrees of genetic relatedness in a large, population-based sample to examine the extent to which any selection factors are due to shared genetic liability (among mothers and their offspring) and environmental factors.

The results of the study support two main conclusions. First, the results provide support for the social influence hypothesis—the association between early maternal age at first childbirth is independently associated with offspring antisocial behavior. We found offspring born to mothers who begin childbearing earlier were more likely to be convicted of a crime than offspring born to mothers who delayed childbearing. The findings from comparisons of differentially exposed cousins born to MZ twin sisters provide support for a causal association between MAFB and offspring criminal convictions. The association is independent of genetic factors passed down from mothers to their offspring, environmental factors shared by cousins, and a number of measured covariates, including paternal age at childbearing, as well as maternal and paternal education level and history of criminal conviction. In the linear models, every year that childbearing was delayed reduced the odds of offspring criminal convictions by approximately 10%. In the binary models, offspring born to mothers who began childbearing as teenagers were 1.4 times more likely to be convicted of any crime than offspring born to mothers who delayed childbearing until adulthood. Importantly, the results from the sensitivity analyses using specific types of criminal convictions—violent, nonviolent, driving- and drug-related convictions—showed similar patterns of association. Consistent with the social influence hypothesis, these results suggest the association between MAFB and offspring criminality persists across many types of criminal behavior.

Second, the pattern of results from the children-of-twins comparisons (e.g., DZ and MZ comparisons) do not suggest genetic factors from passive gene-environment correlation account for the association between MAFB and offspring outcomes. The causal relationship may be better explained by environmental factors specifically associated with early maternal age at first childbirth, such as diminished financial and social resources in families in which the mother had her first child at an early age (Nagin, et al., 1997). Behavior genetics studies have found that maternal age at first birth is heritable (Rodgers, et al., 2007), which suggests that genetic factors may be associated with early age at first childbirth. The current findings, however, reiterate how the mechanisms that influence a putative risk factor (early maternal age first childbirth) are separate from the mechanisms through which the risk factor is associated with an outcome (Rutter, et al., 1993).

The results from the current study may help to explain the discrepant findings from previous studies. Some studies using cousin-comparisons found that selection effects best accounted of the association between MAFB and poor offspring outcomes (Geronimus, et al., 1994; Turley, 2003). Our results from a much larger, population-based sample, provide support for

a causal association (the social influence hypothesis), rather than the influence of selection effects. Other studies found support for a causal association but were either using children-of-twins design to test the effect of maternal age at focal birth on offspring mental health outcomes (Harden, et al., 2007) or using sibling-comparisons to test the effect of maternal age at focal birth on offspring behavior problems (D'Onofrio, et al., 2009). The results from the current study suggest that the effect of maternal age at first birth could help account for the statistical association between maternal age at focal birth and offspring criminal convictions in the entire population (Coyne, Långström, Lichtenstein, & D'Onofrio, submitted for review). Therefore, the lack of difference between early- and later-born siblings born to women who were teenagers when they first gave birth could be due to the carry-over effect of MAFB on all siblings in a nuclear family (Coyne & D'Onofrio, in press).

The results provide support for the causal association between MAFB and offspring criminal outcomes but this does not clarify what factors mediate that association. Previous studies have identified low socioeconomic status, large family size, caretaker changes and parental criminal convictions as mediators explaining the effect of early maternal age at first birth (Jaffee, et al., 2001; Nagin, et al., 1997; Pogarsky, et al., 2006). Future studies will need to explore these family-level risk factors as potential mediators. Identifying the processes associated with early age at first birth that increased the risk of poor offspring outcomes will be essential for creating effective and efficient interventions.

Limitations

First, public health services, social attitudes about teenage sexuality in Sweden, relative lack of racial and ethnic diversity in Sweden may make generalizations from these results to other countries, such as the United States, difficult. Teenage childbirth is quite rare in Sweden compared to other countries (Singh & Darroch, 2000). Therefore the young women who give birth as teenagers in Sweden may constitute a uniquely, high-risk population of young mothers. More cross-national research is needed to identify which risk factors predict teenage childbirth and account for potential heterogeneity among teenage mothers.

Second, children-of-siblings and children-of-twins designs are not randomized controlled experiments and cannot determine conclusively if the association is causal. The association between maternal age at first birth and offspring criminal convictions could be due to non-shared environmental factors at the twin level (e.g., factors that make twin sisters dissimilar) (D'Onofrio, et al., 2003). Similarly, the children-of-siblings and children-of-twins designs do not account for genetic risk contributed by the fathers of the offspring (Eaves, et al., 2005). We used statistical covariates to account for factors unique to each child (paternal age at childbearing), the mothers' and fathers' criminal history and highest level of educational attainment to help address these concerns. It is impossible, however, to know if we accounted for every salient confounding factor. And, the current study does not include as many statistical covariates, when compared to smaller, more intensively studied sample. We, therefore, encourage researchers to replicate the findings using other children of siblings and twin datasets, as well as other quasi-experimental designs (e.g., adoption studies) with good measurement. Strong causal inferences can only be made when converging results are found using multiple studies and designs (Rutter et al., 2001).

Third, these designs assume there is no assortative mating (e.g., non-random mate selection for the phenotype being studied). If young women who begin childbearing early exhibit higher levels of antisocial behavior and seek out antisocial partners, their offspring would have both increased genetic risk for later antisocial behavior as well as increased environmental exposure to parental antisocial behavior. Future studies should include paternal measures to identify whether the effect of MAFB on offspring criminal convictions

is due to genetic and environmental contributions from the mates selected by younger mothers compared to older mothers.

Fourth, these designs assume equal environments among all relative groups. This means that differences in risk among offspring would not be due to greater contact between offspring from MZ sisters' families than DZ sisters' families or full sisters' families (D'Onofrio, et al., 2003).

Finally, the measure of antisocial behavior we used may not be the best estimate of true antisocial tendencies. We used registered criminal convictions as measure of antisocial behavior. Since the age of criminal responsibility in Sweden is 15 years, children under age 15 years cannot be convicted and only criminal behavior from mid-adolescence into adulthood was possible to capture in the current study. However, using official criminal convictions did not necessarily affect the magnitude of the association between teenage childbirth and offspring criminal behavior, because previous studies suggest the relative risks obtained with self-report and official conviction records overlap considerably (Arseneault, Moffitt, Caspi, Taylor, & Silva, 2000). Previous studies using the current sample have also found converging results to the findings on criminal convictions when exploring related constructs, such as low intellectual abilities, assessment of personality traits, and substance use problems (D'Onofrio et al., 2010; Lambe, Hultman, Torrang, MacCabe, & Cnattingius, 2006). Future quasi-experimental research using more precise measures of antisocial behavior, though, should be conducted in the future.

Conclusion

Teenage childbearing is internationally recognized as a public health issue with serious consequences for young mothers and their children. The current study is the first we are aware of to use a large national sample with diversity in maternal age at first birth to test causal hypotheses regarding the association between maternal age at first birth and offspring criminal convictions. Contrary to previous findings the current study suggests the association between teenage childbearing and offspring criminal convictions is, to a large extent, causal. The results support the social influence hypothesis that early childbearing disrupts important maternal development that subsequently increases the likelihood of offspring criminal convictions. Therefore, delaying first birth could be a useful strategy for reducing poor outcomes for offspring.

The study combined multiple quasi-experimental designs to rule out possible genetic and environmental confounds shared within nuclear families. These rigorous children-of-siblings and children-of-twins comparisons may help to resolve some of the discrepancies in previous studies that were unable to control for risk factors shared by all siblings in a family. Using comparisons of offspring born to MZ, the current study was able to account for confounds that are shared among cousins and environmental confounds that make adult siblings similar.

Future research is needed to replicate and extend these findings. Replication studies using genetically informative samples from different nations will provide converging evidence and allow for cross-national comparisons of the patterns of association. Additionally, exploring what processes mediate the causal association, such as poor parenting, large family size, or financial deprivation, will be essential for developing effective prevention and intervention programs that can ameliorate the negative effects of early maternal age at childbirth.

References

- Alan Guttmacher Institute. US teenage pregnancy statistics: National and state trends and trends by race and ethnicity. New York: Author; 2010.
- Arseneault L, Moffitt TE, Caspi A, Taylor P, Silva P. Mental disorders and violence in a total birth cohort: Results from the Dunedin Study. *Archives of General Psychiatry*. 2000; 57:979–986. [PubMed: 11015816]
- Centers for Disease Control and Prevention. Preventing Teen Pregnancy in the US. Atlanta: Apr. 2011 Retrieved from <http://www.cdc.gov/VitalSigns/pdf/2011-04-vitalsigns.pdf>
- Chen XK, Wen SW, Fleming N, Demissie K, Rhoads GG, Walker M. Teenage pregnancy and adverse birth outcomes: a large population based retrospective cohort study. *International Journal of Epidemiology*. 2007; 36:368–373. [PubMed: 17213208]
- Coley RL, Chase-Lansdale PL. Adolescent pregnancy and parenthood: Recent evidence and future directions. [Peer Reviewed]. *American Psychologist*. 1998; 53(2):152–166.10.1037/0003-066x.53.2.152 [PubMed: 9491745]
- Coyne CA, D’Onofrio BM. Some (but not much) progress toward understanding teenage childbearing: A review of research from the past decade. *Advances in Child Development and Behavior*. :442. (in press).
- Coyne, CA.; Långström, N.; Lichtenstein, P.; D’Onofrio, BM. Effect of adolescent motherhood on offspring criminality risk: National cohort study over 30 years. (submitted for review)
- Coyne CA, Långström N, Lichtenstein P, D’Onofrio BM. Association between teenage motherhood and offspring criminality risk: National cohort study over 30 years. *Journal of Child Psychology and Psychiatry*. (submitted for review).
- D’Onofrio, BM. Children of Twins Design. In: Everitt, BS.; Howell, DC., editors. *Encyclopedia of Statistics in Behavioral Science*. Vol. 1. Chichester: John Wiley & Sons, Ltd; 2005. p. 256-258.
- D’Onofrio BM, Goodnight JA, Van Hulle CA, Rodgers JL, Rathouz PJ, Waldman ID, Lahey BB. Maternal age at childbirth and offspring disruptive behaviors: Testing the causal hypothesis. *Journal of Child Psychology and Psychiatry*. 2009; 50(8):1018–1028. [PubMed: 19281603]
- D’Onofrio BM, Singh AL, Iliadou A, Lambe M, Hultman CM, Neiderhiser JM, Lichtenstein P. A Quasi-Experimental Study of Maternal Smoking During Pregnancy and Offspring Academic Achievement. *Child Development*. 2010; 81(1):80-80, 100. [PubMed: 20331655]
- D’Onofrio BM, Turkheimer E, Eaves LJ, Corey LA, Berg K, Solaas MH. The role of Children of Twins design in elucidating causal relations between parent characteristics and child outcomes. *Journal of Child Psychology and Psychiatry*. 2003; 44:1130–1144. [PubMed: 14626455]
- D’Onofrio BM, Turkheimer E, Emery RE, Maes HH, Silberg J, Eaves LJ. A Children of Twins Study of parental divorce and offspring psychopathology. *Journal of Child Psychology and Psychiatry*. 2007; 48(7):667–675. [PubMed: 17593147]
- D’Onofrio BM, Turkheimer E, Emery RE, Slutske WS, Heath AC, Madden PA, Martin NG. A Genetically Informed Study of Marital Instability and Its Association With Offspring Psychopathology. *Journal of Abnormal Psychology*. 2005; 114(4):570–586. [PubMed: 16351381]
- D’Onofrio BM, Goodnight J, Van Hulle CA, Waldman ID, Rodgers JL, Harden KP, Lahey BB. Maternal age at childbirth and childhood conduct problems: Strengthening the causal inference. *Psychological Science*. 2009
- Danielsson, M.; Rogala, C.; Sundstrom, K. Teenage sexual and reproductive behavior in developed countries: Country report for Sweden. New York: The Alan Guttmacher Institute; 2001.
- Darroch JE, Singh S, Frost JJ. Differences in teenage pregnancy rates among five developed countries: The roles of sexual activity and contraceptive use. *Family Planning Perspectives*. 2001; 33(6):244–250. [PubMed: 11804433]
- Donovan SJ, Susser E. Commentary: Advent of sibling designs. *International Journal of Epidemiology*. 2011; 40:345–349. [PubMed: 21450688]
- Eaves LJ, Silberg J, Maes HH. Revisiting the children of twins: Can they be used to resolve the environmental effects of dyadic parental treatment on child behavior? *Twin Research*. 2005; 8:283–290.

- Ekeus C, Christensen K, Hjern A. Unintentional and violent injuries among pre-school children of teenage mothers in Sweden: a national cohort study. *Journal of Epidemiology and Community Health*. 2004; 58:680–685. [PubMed: 15252071]
- Fazel S, Grann M. The population impact of severe mental illness on violent crime. *American Journal of Psychiatry*. 2006; 163:1397–1403. [PubMed: 16877653]
- Fazel S, Långström N, Hjern A, Grann M, Lichtenstein P. Schizophrenia, substance abuse, and violent crime. *JAMA: Journal of the American Medical Association*. 2009; 301(19):2016–2023.
- Fergusson DM, Woodward LJ. Maternal age and educational and psychosocial outcomes in early adulthood. *Journal of Child Psychology and Psychiatry and Allied Disciplines*. 1999; 40(3):479–489.
- Geronimus AT, Korenman S, Hillemeier MM. Does young maternal age adversely affect child development? Evidence from cousin comparisons in the United States. *Population and Development Review*. 1994; 20(3):585–609.
- Harden KP, Lynch SK, Turkheimer E, Emery RE, D’Onofrio BM, Slutske WS, Martin NG. A behavior genetic investigation of adolescent motherhood and offspring mental health problems. *Journal of Abnormal Psychology*. 2007; 116(4):667–683. [PubMed: 18020715]
- Heath AC, Kendler KS, Eaves LJ, Markell D. The resolution of cultural and biological inheritance: Informativeness of different relationships. *Behavior Genetics*. 1985; 15(5):439–465. [PubMed: 4074271]
- Hoffman, S. By the numbers: The public costs of teen childbearing. Washington, D. C: National Campaign to Prevent Teen Pregnancy; 2006.
- Jaffee S, Caspi A, Moffitt TE, Belsky J, Silva P. Why are children born to teen mothers at risk for adverse outcomes in young adulthood? Results from a 20-yr longitudinal study. *Development and Psychopathology*. 2001; 13(2):377–397. [PubMed: 11393652]
- Jaffee S, Strait L, Odgers CL. From correlates to causes: Can quasi-experimental studies and statistical innovations bring us closer to identifying the causes of antisocial behavior? *Psychological Bulletin*. (in press).
- Lahey BB, D’Onofrio BM. All in the family: Comparing siblings to test causal hypotheses regarding environmental influences on behavior. *Current Directions in Psychological Science*. 2010; 19:319–323. [PubMed: 23645975]
- Lahey, BB.; Moffitt, TE.; Caspi, A., editors. *Causes of conduct disorder and juvenile delinquency*. New York: Guilford; 2003.
- Lambe M, Hultman CM, Torrang A, MacCabe J, Cnattingius S. Maternal smoking during pregnancy and school performance at age 15. *Epidemiology*. 2006; 17(5):524–530. [PubMed: 16878043]
- Långström N, Grann M, Ruchkin V, Sjöstedt G, Fazel S. Violent offending in autism spectrum disorder: National study of risk factors among hospitalised individuals. *Journal of Interpersonal Violence*. 2008
- Levine JA, Emery CR, Pollack H. The Well-Being of Children Born to Teen Mothers. *Journal of Marriage and Family*. 2007; 69(1):105–122.
- Lichtenstein P, Sullivan PF, Cnattingius S, Gatz M, Johansson S, Carlstrom E, Pederson NL. The Swedish Twin Registry in the Third Millennium: An Update. *Twin Research and Human Genetics*. 2006; 9(6):875–882. [PubMed: 17254424]
- Nagin DS, Pogarsky G, Farrington DP. Adolescent mothers and the criminal behavior of their children. *Law & Society Review*. 1997; 31(1):137–162.
- Olausson PO, Haglund B, Weitoft GR. Teenage childbearing and long-term socioeconomic consequences: A case study in Sweden. *Family Planning Perspectives*. 2001; 33(2):70–74. [PubMed: 11330853]
- Olausson PO, Haglund B, Weitoft GR, Cnattingius S. Premature death among teenage mothers. *International Journal of Obstetrics and Gynaecology*. 2004; 111:793–799.
- Pogarsky G, Lizotte AJ, Thornberry TP. The delinquency of children born to young mothers: Results from the Rochester Youth Development Study. *Criminology*. 2003; 41(4):1249–1286.
- Pogarsky G, Thornberry TP, Lizotte AJ. Developmental Outcomes for Children of Young Mothers. *Journal of Marriage and Family*. 2006; 68(2):332–344.

- Rodgers JL, Bard DE, Miller WB. Multivariate Cholesky models of human female fertility patterns in the NLSY. *Behavior Genetics*. 2007; 37(2):345–361. [PubMed: 17205393]
- Rutter, M. Gene-environment interplay and developmental psychopathology. New York, NY: Taylor & Francis Group/Lawrence Erlbaum Associates; 2007.
- Rutter, M.; Belsky, J.; Brown, G.; Dunn, J.; D'Onofrio, B.; Eekelaar, J.; Witherspoon, S. Social sciences and family policies. London: British Academy Policy Centre; 2010.
- Rutter M, Pickles A, Murray R, Eaves L. Testing hypotheses on specific environmental causal effects on behavior. *Psychological Bulletin*. 2001; 127(3):291–291–324.10.1037/0033-2909.127.3.291 [PubMed: 11393298]
- Rutter, M.; Silberg, J.; Simonoff, E. Whither behavioral genetics? A developmental psychopathological perspective. Washington, DC, US: American Psychological Association; 1993.
- Scarr S, McCartney K. How people make their own environments: A theory of genotype->environment effects. *Child Development*. 1983; 54:424–435. [PubMed: 6683622]
- Shadish, WR.; Cook, TD.; Campbell, DT. Experimental and quasi-experimental designs for generalized causal inference. Belmont, CA: Wadsworth Cenage Learning; 2002.
- Silberg J, Eaves LJ. Analyzing the contribution of genes and parent-child interaction to childhood behavioral and emotional problems: A model for the children of twins. *Psychological Medicine*. 2004; 34:347–356. [PubMed: 14982140]
- Singh S, Darroch JE. Adolescent pregnancy and childbearing: Levels and trends in developed countries. *Family Planning Perspectives*. 2000; 32(1):14–23. [PubMed: 10710702]
- Statistics Sweden. Multi-generation Register 2005. A description of contents and quality. Statistics Sweden, Background Facts. 2006. Retrieved from http://www.scb.se/statistik/_publikationer/BE9999_2005A01_BR_BE96ST0606.pdf
- Sweden, S. Utbildningsregistret. 2004. Retrieved from http://www.scb.se/statistik/UF/UF0506/_dokument/UF0506_DO_2004.pdf
- Turley RNL. Are children of young mothers disadvantaged because of their mother's age or family background? *Child Development*. 2003; 74:465–474. [PubMed: 12705567]
- West SG. Alternatives to Randomized Experiments. [Article]. *Current Directions in Psychological Science* (Wiley-Blackwell). 2009; 18(5):299–304.10.1111/j.1467-8721.2009.01656.x
- Woodward LJ, Fergusson DM. Childhood peer relationship problems and psychosocial adjustment in late adolescence. [Peer Reviewed]. *Journal of Abnormal Child Psychology*. 1999; 27(1):87–104.10.1023/a:1022618608802 [PubMed: 10197409]

APPENDIX

Figure 1.
Comparing linear and quadratic models predicting criminal convictions for unrelated offspring

Figure 1.

Hypothetical patterns of results consistent with (A) a causal association, (B) a statistical association confounded by genetic factors, and (C) a statistical association confounded by environmental factors

Figure 2.
Flowchart of participant inclusion and exclusion criteria

Figure 3.
Hazard ratios with 95% CIs for ordinal survival models

Figure 4. Hazard ratios with 95% CIs for survival models with (A) linear measure of MAFB and (B) binary measure of MAFB (teenage versus adult first birth) as predictors of offspring criminal convictions

Table 1

Demographic characteristics of offspring and families

Variable	All Mothers		Teen Mothers		Adult Mothers	
	N	(M)%	N	(M)%	N	(M)%
Mean maternal age at first birth		(24.2)		(18.7)		(26.1)
Unique mothers	535779	100%	58488	9.8%	541404	90.3%
Offspring covariates						
Offspring Gender						
Female	529465	48.7%	74610	48.8%	454855	48.7%
Offspring birth order						
1st born (reference)	88244	8.1%	6954	4.5%	81290	8.7%
2nd born	510213	46.9%	38514	25.2%	471699	50.5%
3rd born	338590	31.1%	54818	35.9%	283772	30.4%
4th born or later	150751	13.9%	52561	34.3%	98190	10.5%
Father's age at birth						
Mean age		(29.6)		(26.8)		(30.1)
< 20 years old	12805	1.2%	9569	6.26	3236	0.4%
20–24 years old	188159	17.3%	56385	36.9%	131774	14.1%
25–29 years old (ref)	415903	38.2%	47183	30.8%	374623	40.1%
30–35 years old	304402	28.0%	24143	15.8%	280259	30.0%
> 35 years old	158697	14.6%	13638	8.9%	145059	15.5%
Missing father's age	7832	0.7%	1929	1.3%	5903	0.6%
Parental covariates						
Maternal educational achievement						
Less than 9 years of education (ref)	1767	0.3%	702	1.2%	1065	0.2%
At least 9 years of education	533137	99.5%	57528	98.4%	475609	99.7%
Missing education level	875	0.2%	258	0.4%	617	0.1%
Paternal educational achievement						
Less than 9 years of education (ref)	18414	3.4%	5340	7.6%	13074	2.7%
At least 9 years of education	529552	95.9%	65124	91.0%	464438	97.0%
Missing education level	3850	0.7%	1090	1.5%	2760	0.6%

Variable	All Mothers		Teen Mothers		Adult Mothers	
	N	(M)%	N	(M)%	N	(M)%
Maternal criminal history						
Any criminal conviction	67406	12.6%	12522	21.4%	54884	11.5%
Paternal criminal history						
Any criminal conviction	247997	44.9%	43508	60.8%	204489	42.6%

Note: Total offspring N =1,084,939 for analyses

Table 2

Parameter estimates and standard errors for survival models with linear MAFB predictor of offspring criminal convictions

Outcome	Model 1 ^a		Model 2 ^a		Model 3 ^b		Model 4 ^c		Model 5 ^d		Model 6 ^e	
	b	SE	b	SE	b	SE	b	SE	b	SE	b	SE
MAFB (per year)	-0.09 *	<0.01	-0.07 *	<0.01	-0.05 *	<0.01	-0.10 *	0.02	-0.10 *	0.02	-0.09 *	0.02
Gender (Female)	-0.96 *	0.01	-0.98 *	0.01	-0.98 *	0.01	-1.02 *	0.10	-1.11 *	0.12	-1.12 *	0.12
Father's age												
< 20 years old	0.35 *	0.02	0.25 *	0.02	0.20 *	0.03	-0.11	0.34	0.68 *	0.31	0.61	0.32
20-24 years old	0.15 *	0.01	0.12 *	0.01	0.09 *	0.01	0.08	0.12	<0.01	0.14	-0.07	0.14
25-29 years old (ref)	-	-	-	-	-	-	-	-	-	-	-	-
30-35 years old	-0.01	0.01	-0.02 *	0.01	-0.03 *	0.01	0.16	0.11	0.15	0.12	0.11	0.00
> 35 years old	0.10 *	0.01	0.05 *	0.01	-0.03	0.02	0.04	0.15	0.04	0.16	-0.03	0.12
Missing father's age	0.36 *	0.03	0.24 *	0.04	0.13 *	0.06	0.28	0.38	0.38	0.47	0.50	0.60
Offspring birth order												
1st born (reference)	-	-	-	-	-	-	-	-	-	-	-	-
2nd born	-0.32 *	0.01	-0.19 *	0.01	-0.17 *	0.02	-0.10	0.16	-0.24	0.18	-0.19	0.17
3rd born	-0.36 *	0.01	-0.21 *	0.01	-0.17 *	0.03	-0.36 *	0.17	-0.41	0.19	-0.34	0.19
4th born or later	-0.21 *	0.01	-0.12 *	0.12	-0.09 *	0.03	-0.22	0.19	-0.40	0.22	-0.39	0.22
Parental covariates												
Maternal educational achievement												
Less than 9 years of education (ref)	-	-	-	-	-	-	-	-	-	-	-	-
At least 9 years of education			-0.24 *	0.03							-0.18	0.73
Missing education level			0.01	0.06							-10.43 *	1.23
Paternal educational achievement												
Less than 9 years of education (ref)	-	-	-	-	-	-	-	-	-	-	-	-
At least 9 years of education			-0.14 *	0.01							-0.34	0.21
Missing education level			0.24 *	0.03							-0.41	0.50
Maternal criminal history			0.54 *	0.01							0.51 *	0.13
Paternal criminal history			0.56 *	0.01							0.52 *	0.10

Note. Model 1 compares unrelated offspring. Model 2 compares unrelated offspring with family covariates. Model 3 compares offspring of full sisters (cousins). Model 4 compares offspring of DZ twin sisters. Model 5 compares offspring of MZ twin sisters. Model 6 compares offspring of MZ twin sisters with family covariates. The parameters are distributed as logits.

^aBased on n=1,084,939.

^bBased on fixed effects model examining differentially exposed offspring of full sisters (n=337,880).

^cBased on fixed effects model examining differentially exposed offspring of DZ twin sisters (n=3,870).

^dBased on fixed effects model examining differentially exposed offspring of MZ twin sisters (n=3,172).

^eBased on fixed effects model examining differentially exposed offspring of MZ twin sisters with no missing covariate data (n=3,172).

* p<.05.

Table 3

Parameter estimates and standard errors for survival models with binary MAFB predictor of offspring criminal convictions

Outcome	Model 1 ^a		Model 2 ^a		Model 3 ^b		Model 4 ^c		Model 5 ^d		Model 6 ^e	
	b	SE	b	SE	b	SE	b	SE	b	SE	b	SE
MAFB (teenage)	0.49*	0.01	0.36*	0.01	0.29*	0.02	0.67*	0.12	0.44*	0.14	0.34*	0.14
Gender (Female)	-0.96*	0.01	-0.98	0.01	-0.98	0.01	-1.03	0.10	-1.11*	0.12	-1.12*	0.11
Father's age												
< 20 years old	0.41*	0.02	0.30	0.02	0.22	0.03	-0.07	0.34	0.91*	0.31	0.82*	0.29
20-24 years old	0.22*	0.01	0.18	0.01	0.11	0.01	0.16	0.12	0.14	0.14	0.06	0.13
25-29 years old (ref)	-	-	-	-	-	-	-	-	-	-	-	-
30-35 years old	-0.12*	0.01	-0.10	0.01	-0.06	0.01	0.05	0.11	0.02	0.12	<0.01	0.12
> 35 years old	-0.06*	0.01	-0.08	0.01	-0.09	0.02	-0.12	0.15	-0.13	0.15	-0.19	0.17
Missing father's age	0.37*	0.03	0.24	0.03	0.13	0.06	0.29	0.39	0.43	0.48	0.49	0.55
Offspring birth order												
1st born (reference)	-	-	-	-	-	-	-	-	-	-	-	-
2nd born	-0.27*	0.01	-0.02	0.01	-0.13	0.02	-0.05	0.16	-0.17	0.18	-0.12	0.19
3rd born	-0.24*	0.01	-0.12	0.01	-0.09	0.02	-0.23	0.17	-0.26	0.19	-0.19	0.19
4th born or later	-0.06*	0.01	0.00	0.01	0.01	0.03	-0.07	0.19	-0.09	0.21	-0.10	0.21
<i>Parental covariates</i>												
Maternal educational achievement												
Less than 9 years of education (ref)	-	-	-	-	-	-	-	-	-	-	-	-
At least 9 years of education			-0.25	0.03							-0.16	0.74
Missing education level			0.02	0.06							-10.23	248.31
Paternal educational achievement												
Less than 9 years of education (ref)	-	-	-	-	-	-	-	-	-	-	-	-
At least 9 years of education			-0.19	0.01							-0.44	0.22
Missing education level			0.21	0.03							-0.43	0.53
Maternal criminal history			0.55	0.01							0.55	0.12
Paternal criminal history			0.59	0.01							0.54	0.10

Note. Model 1 compares unrelated offspring. Model 2 compares unrelated offspring with family covariates. Model 3 compares offspring of full sisters (cousins). Model 4 compares offspring of DZ twin sisters. Model 5 compares offspring of MZ twin sisters. Model 6 compares offspring of MZ twin sisters with family covariates. The parameters are distributed as logits.

^aBased on $n=1,084,939$.

^bBased on fixed effects model examining differentially exposed offspring of full sisters ($n=337,880$).

^cBased on fixed effects model examining differentially exposed offspring of DZ twin sisters ($n=3,870$).

^dBased on fixed effects model examining differentially exposed offspring of MZ twin sisters ($n=3,172$).

^eBased on fixed effects model examining differentially exposed offspring of MZ twin sisters with no missing covariate data ($n=3,172$).

* $p<.05$.

Table 4

Parameter estimates and standard errors from linear model testing zygosity as a moderator

Outcome	Models	
	b	SE
Any criminal conviction		
Age at first birth (family mean)	-0.11 *	0.00
Age at first birth effect for MZ twins (deviation)	-0.06 *	0.03
Age at first birth deviation for DZ twins (deviation * zyg)	-0.01	0.03
Zygosity (MZ=0)	-0.12	0.72
Violent convictions		
Age at first birth (family mean)	-0.18 *	0.03
Age at first birth effect for MZ twins (deviation)	-0.09 *	0.07
Age at first birth deviation for DZ twins (deviation * zyg)	0.01	0.08
Zygosity (MZ=0)	-0.01	0.15
Nonviolent convictions		
Age at first birth (family mean)	-0.10 *	0.02
Age at first birth effect for MZ twins (deviation)	-0.10 *	0.04
Age at first birth deviation for DZ twins (deviation * zyg)	0.00	0.05
Zygosity (MZ=0)	-0.05	0.11
Driving-related convictions		
Age at first birth (family mean)	-0.15 *	0.03
Age at first birth effect for MZ twins (deviation)	-0.06 *	0.08
Age at first birth deviation for DZ twins (deviation * zyg)	0.01	0.10
Zygosity (MZ=0)	-0.31	0.20
Drug-related convictions		
Age at first birth (family mean)	-0.11 *	0.03
Age at first birth effect for MZ twins (deviation)	-0.12 *	0.09
Age at first birth deviation for DZ twins (deviation * zyg)	0.03 *	0.10
Zygosity (MZ=0)	-0.08	0.21

Note. Based on models comparing differentially exposed offspring of MZ and DZ twin sisters (n=7,042) for criminal outcomes.

*
p<.05.

Table 5

Parameter estimates and standard errors from binary model testing zygosity as a moderator

Outcome	Models	
	b	SE
Any criminal conviction		
Teenage first birth (family mean)	0.83 *	0.10
Teenage first birth effect for MZ twins (deviation)	0.13	0.22
Teenage first birth deviation for DZ twins (deviation * zyg)	0.21	0.28
Zygosity (MZ=0)	-0.11	0.07
Violent convictions		
Teenage first birth (family mean)	1.39 *	0.19
Teenage first birth effect for MZ twins (deviation)	0.25	0.46
Teenage first birth deviation for DZ twins (deviation * zyg)	-0.33	0.55
Zygosity (MZ=0)	-0.04	0.15
Nonviolent convictions		
Teenage first birth (family mean)	-0.50 *	0.17
Teenage first birth effect for MZ twins (deviation)	0.48	0.34
Teenage first birth deviation for DZ twins (deviation * zyg)	-0.10	0.44
Zygosity (MZ=0)	-0.04	0.12
Driving-related convictions		
Teenage first birth (family mean)	0.82 *	0.25
Teenage first birth effect for MZ twins (deviation)	0.44	0.62
Teenage first birth deviation for DZ twins (deviation * zyg)	-0.75	0.83
Zygosity (MZ=0)	-0.29	0.20
Drug-related convictions		
Teenage first birth (family mean)	0.89 *	0.30
Teenage first birth effect for MZ twins (deviation)	0.79	0.51
Teenage first birth deviation for DZ twins (deviation * zyg)	-0.07	0.67
Zygosity (MZ=0)	-0.10	0.22

Note. Based on models comparing differentially exposed offspring of MZ and DZ twin sisters (n=7,042) for criminal outcomes.

*
p<.05.