FA-05 Fertility, family formation and the modern life course

The transition to below-replacement fertility stands as one of the most profound demographic realignments in human history. With the exception of a few outlier nations, almost all developed countries now exhibit a Total Fertility Rate (TFR) significantly below the replacement level of 2.1 children per woman. In Europe, the TFR has persistently hovered around 1.4 to 1.5, with Germany experiencing a temporary, slight recuperation in the 2010s before declining back to roughly 1.4 by 2022[1]. East Asia presents an even more extreme trajectory of demographic collapse, exemplified by South Korea's unprecedented TFR of 0.72 in 2023, accompanied by massive state expenditure failing to arrest the decline[3].

To comprehend this phenomenon, demographic research cannot rely on single-discipline explanations. The modern life course represents an unprecedented collision between our evolutionary biology and the structural realities of contemporary socio-economic systems. This report provides an exhaustive, expert-level analysis of fertility and family formation by separating the evidence into three distinct layers: Physiology, representing the measurable biological constraints of reproduction; Behaviour, capturing the statistical outcomes of economic and social decision-making; and Culture, exploring the variable institutional and normative frameworks that shape human environments.

Layer 1: Physiology (Measurable Constraints)

The foundational layer of human fertility is physiological. The biological parameters of reproduction were optimized in ancestral environments where the onset of reproduction closely followed puberty. The modern life course, which mandates prolonged periods of education, delayed partnering, and extended early-career establishment, fundamentally mismatches this biological schedule.

Female Reproductive Biology and the Ovarian Reserve

The female reproductive lifespan is strictly bound by the finite nature of the ovarian reserve. Non-growing follicles (NGFs), which represent the human ovarian reserve, are established before birth and continuously deplete until menopause, typically reached at an average age of 50 to 51 years[5].

In a landmark meta-analysis and modeling study published in *PLoS ONE*, Wallace and Kelsey (2010) synthesized data from eight independent quantitative histological studies comprising 325 human ovaries to construct a comprehensive mathematical model of NGF decline from conception to menopause[5]. Utilizing a five-parameter Asymmetric Double-Gaussian Cumulative (ADC) curve, the authors demonstrated that 81% of the variance in NGF populations is attributable to age alone, highlighting a rigid physiological timeline[6]. The physiological reality modeled by Wallace and Kelsey is stark. The average female fetus possesses a peak population of approximately 300,000 NGFs per ovary at 18 to 22 weeks gestation, though the 95% prediction interval is vast, spanning from 35,000 to 2,534,000

NGFs[6]. Post-birth, the depletion accelerates. By age 30, only 12% of the maximum pre-birth NGF population remains present in the average woman[6]. By age 40, a mere 3% of the reserve remains intact[6].

While the average trajectory of decline is mathematically predictable, it is critical to distinguish population averages from individual fecundity. Research by Steiner et al. (2017) published in the *Journal of the American Medical Association (JAMA)* indicates that while ovarian reserve biomarkers, such as Anti-Müllerian Hormone (AMH), decline predictably with age, they are surprisingly poor predictors of short-term fecundity in older women who do not have a diagnosed history of clinical infertility[8]. Therefore, at the individual level, a low ovarian reserve does not automatically equate to immediate sterility. The statistical probability of conception for the average cohort drops precipitously in the late thirties, but individual distributions overlap significantly, allowing many women with statistically diminished reserves to conceive naturally.

Male Reproductive Biology: Sperm Decline and Paternal Age

Historically, the burden of age-related fertility decline was placed almost exclusively on women. However, robust epidemiological and physiological evidence confirms that male fertility also degrades with age and environmental exposures.

Dunson, Baird, and Colombo (2004), publishing in *Human Reproduction*, established that while male sperm quality begins to demonstrate measurable declines beyond the age of 35, severe impacts on conception probabilities are typically not observed until men reach the age of fifty[8]. However, the more pressing physiological concern relates to genetic integrity rather than mere conception probability. Unlike female oocytes, which are suspended in meiosis from fetal development, male spermatogenesis is a continuous process requiring constant cellular division throughout a man's life. This makes the male germline highly susceptible to replication errors over time.

A landmark genomic paper by Kong et al. (2012) in *Nature*, utilizing an extraordinary sample size of over 1.4 million individuals across four populations, demonstrated definitively that advancing paternal age is the primary driver of *de novo* genetic mutations in human offspring[10]. These spontaneous mutations decrease overall evolutionary fitness and significantly increase the risk of neurodevelopmental disorders[10]. Building on the implications of paternal age, Reichenberg et al. (2006) published a massive population-based cohort study in the *Archives of General Psychiatry*, examining 2,615,081 individuals born in Sweden[11]. They reported an extraordinary effect size: compared to fathers aged 20 to 24, the offspring of fathers aged 45 and older exhibited a Hazard Ratio (HR) of 3.45 (95% CI 1.62–7.33) for Autism Spectrum Disorder (ASD), alongside massively elevated risks for ADHD (HR=13.13) and bipolar disorder (HR=24.70)[11]. This finding has been widely replicated globally, cementing advanced paternal age as a measurable physiological risk factor; for instance, independent case-control studies in Jamaica by Rahbar et al. have confirmed joint maternal and paternal age effects, and cross-sectional studies in Bangladesh have similarly replicated the elevated autism risk for fathers over 40[12].

Simultaneously, a highly contested area of male physiology is the reported global decline in sperm counts. Levine et al. (2017) published a systematic review and meta-regression in *Human*

Reproduction Update involving 185 studies and 42,935 men. They reported a 52.4% decline in sperm concentration and a 59.3% decline in total sperm count among unselected Western men between 1973 and 2011, with a calculated decline rate of 1.4% per year[15]. Their 2023 update expanded the dataset globally and suggested this trend had actually accelerated post-2000[15]. Regional studies corroborate these vulnerabilities; Jørgensen et al. (2012) in *BMJ Open* found that only 23% of a sample of 301 young Danish men possessed optimal semen quality, with 42% possessing suboptimal quality[19].

However, this systemic decline is heavily contested. Leading critics, such as Boulicault and the Harvard GenderSci Lab, argue that the meta-regression methodology utilized by Levine and colleagues relies too heavily on historical data with varied collection methods. They posit that older historical baselines used different laboratory counting techniques (such as earlier hemocytometers versus modern counting chambers), which may artificially inflate the appearance of a historical decline[15]. Furthermore, recent localized analyses utilizing strict modern controls among unselected, fertile United States men find no clinically significant downward trend over the past two decades[15]. Therefore, while environmental endocrine disruptors—such as specific phthalates and microplastics—clearly impact individual spermatogenesis, the existential magnitude of the global population-level decline remains an open scientific controversy.

Layer 2: Behaviour (Statistical Outcomes)

While physiology sets the rigid biological constraints, human behaviour—driven by economic incentives, housing markets, delayed partnering, and opportunity costs—determines how those constraints are navigated. The behavioural layer is fundamentally statistical; it operates on overlapping distributions and rational choice rather than absolute biological limits.

The Biological Window versus Educational and Career Timing

The primary friction point of the modern life course is that the physiological optimal window for reproduction, spanning ages 18 to 30, directly overlaps with the years required for higher education, prolonged courtship, and early career establishment.

Habbema, Eijkemans, Leridon, and te Velde (2015), in *Human Reproduction*, provided a crucial statistical model calculating the maximum age couples can start trying to conceive in order to achieve their desired family size, assuming both natural conception and the use of Assisted Reproductive Technology (ART), specifically In Vitro Fertilization (IVF)[22]. Their computer simulation revealed that the modern reliance on ART as a reliable "safety net" for delayed childbearing is statistically unfounded for multi-child families. To achieve a 90% certainty of realizing their family goals without IVF, couples must begin attempting conception at surprisingly early ages. Even with the intervention of IVF, the starting ages only shift upward by approximately three to four years, as ART cannot overcome the fundamental decline in oocyte quality[23].

Desired Family Size	Desired Probability of	Max Female Age to Start (No IVF)	Max Female Age to Start (With IVF)

	Success		
1 Child	90%	32 years	35 years
2 Children	90%	27 years	31 years
3 Children	90%	23 years	28 years
Data derived from Habbema et al., 2015, Human Reproduction[23].			

This creates a massive perception gap. Surveys consistently show that university students drastically overestimate the efficacy of IVF and the duration of female fertility, believing that intervention can easily rescue fertility well into a woman's forties[24]. This informational deficit encourages delayed partnering and postponed family formation, resulting in high rates of involuntary childlessness when couples eventually attempt to conceive at ages where the statistical probability of success has plummeted.

The "Motherhood Penalty" and Labour Market Dynamics

One of the most robustly replicated findings in applied microeconomics is the "motherhood penalty"—the divergence in earnings trajectories between men and women immediately following the birth of their first child. Kleven, Landais, and Søgaard (2019), publishing in the *American Economic Journal: Applied Economics*, utilized an event-study methodology across administrative data to map this divergence. They documented immense cross-country variation: the long-run child penalty in earnings is roughly 20% in egalitarian Denmark, but reaches a staggering 60% in Germany[26].

This penalty occurs not strictly because of unequal pay for equal work in identical roles, but because mothers disproportionately reduce their working hours, shift to family-friendly but lower-paying firms, or exit the labour market entirely to manage childcare[26]. Rational actors facing a 60% permanent earnings penalty will naturally delay or forgo childbearing to accumulate career capital and financial security. Mitigating this penalty requires structural intervention. Raute (2019) demonstrated in the *American Economic Journal: Economic Policy* that firm-level interventions matter profoundly. Analyzing the universe of employed women in Germany (sample size of approximately 20,000 births per month), Raute found that employer-provided childcare reduced the child penalty for high-wage mothers by 4.7 percentage points and significantly shortened career interruptions[28]. Despite these localized successes, structural financial penalties remain a dominant behavioural deterrent across Europe.

Housing, Wealth, and the Quantity-Quality Trade-off

Housing represents the largest single expenditure for most modern families, and the structure

of housing markets dictates family formation timelines. Aksoy (2019) and colleagues have demonstrated a causal, though bifurcated, relationship between house prices and fertility using Structural Vector Autoregression (VAR) models and Toda-Yamamoto causality tests on macroeconomic data[30]. Their findings replicate earlier assertions that increases in house prices lead to a decline in birth rates among renters, who face a tightened budget constraint, while generating a wealth effect that mildly increases fertility among existing homeowners[31].

This dynamic relates closely to the macroeconomic theories of population aging and housing. Mankiw and Weil (1989), in *Regional Science and Urban Economics*, initially hypothesized that aging baby boomers would eventually depress housing prices as they downsized and housing demand fell[32]. Recent empirical work in Germany by Hiller and Lerbs (2016) confirms this mechanism locally, demonstrating that a rising old-age dependency ratio depresses urban real estate prices because the life-cycle demand for living space declines after middle age[32].

However, this aggregate depreciation does not help young cohorts in hyper-concentrated modern economies. Because premium employment is heavily centralized in a few major urban hubs, the localized competition for housing remains fierce for those of reproductive age, functionally acting as a massive economic contraceptive.

These spatial and financial constraints perfectly illustrate the "Quantity-Quality Trade-off," formalized by Gary Becker and H. Gregg Lewis (1973) in the *Journal of Political Economy*[36]. In modern, highly specialized knowledge economies, the required investment—or "quality"—to ensure a child succeeds is astronomically high, comprising expensive housing in optimal school districts, private tutoring, and extensive university tuition. As the marginal cost of producing a high-quality child rises, rational parents continuously reduce the quantity of children they have[36].

The Fertility Gap and the Rise of Childlessness

Because of these competing biological and economic pressures, a massive discrepancy has opened between desired and achieved family sizes. In Europe, the mean ideal family size remains around 2.0 to 2.2 children, yet the achieved TFR is roughly 1.4 to 1.5[2]. Sobotka and Lutz (2010) calculated this "fertility gap" to be approximately 0.35 children per woman across the European Union, representing millions of missing, yet desired, children[22].

Demographically, below-replacement fertility is driven by two main behavioural shifts: the disappearance of large families (three or more children) and a sharp rise in childlessness. Bujard and Sulak (2016) decomposed the German fertility decline in the *Kölner Zeitschrift für Soziologie und Sozialpsychologie*. They found that 68% of the historical drop was due to decreasing higher-order births, while roughly 25.9% was due to an absolute increase in childlessness[38].

Crucially, the demographic profile of childlessness is inverting. Historically, permanent childlessness was concentrated among highly educated women who prioritized professional careers in inflexible, male-dominated work environments, and was a marker of high status[39]. However, recent registry data analyzed by Jalovaara et al. (2019) in the *European Journal of Population* shows a stark societal shift: it is now men and women with the lowest education levels who exhibit the highest proportions of permanent childlessness[40]. This is driven by

rigorous assortative mating and extreme economic precarity. In a dual-income-dependent economy, low-status, low-income men are increasingly marginalized from the marriage and partnership markets entirely, leading to systemic, involuntary childlessness among the working class.

Layer 3: Culture (Variable Institutional Frameworks)

While physiology provides the blueprint and economics provides the immediate incentives, culture—comprising public policy, gender norms, and institutional structures—determines the exact magnitude and permanence of the fertility collapse.

Gender Equity Theory versus Preference Theory

Why does Germany exhibit a larger motherhood penalty than Denmark? Why is South Korea's TFR half that of France's, despite both being highly advanced economies? Theoretical demography relies heavily on Peter McDonald's (2000, 2006) **Gender Equity Theory**, widely published in the *Population and Development Review*[41]. McDonald posits that fertility falls to ultra-low levels in societies where women achieve high levels of gender equity in individual-oriented institutions—such as higher education and the formal labour market—but face persistent, traditional patriarchal inequity in family-oriented institutions, primarily the home and domestic childrearing[41].

When women are socialized to believe they can achieve parity in the boardroom, but are still culturally expected to perform the vast majority of unpaid domestic labour and childcare at home, they face an unmanageable "second shift." The rational response to this cultural contradiction is to strike by withholding fertility[44]. Countries that successfully reform the private sphere and mandate institutional support—like the Nordic nations, which enforce significant paternal leave and provide universal, heavily subsidized childcare—buffer the fertility drop by harmonizing public and private equity.

In contrast, Catherine Hakim (2000) introduced **Preference Theory** in the *British Journal of Sociology*, arguing against macro-structural determinism. Hakim argues that women in affluent societies are inherently heterogeneous in their lifestyle preferences, clustering reliably into three groups: home-centered (approximately 20%), work-centered (approximately 20%), and adaptive (approximately 60%)[45]. Hakim contends that public policies fail when they treat women as a monolith; successful institutions must accommodate the 60% of 'adaptive' women who wish to combine work and family fluidly, without punishing them economically for part-time or intermittent engagement[46].

The Low Fertility Trap

Once a culture drops significantly below the replacement rate, it risks entering what Lutz, Skirbekk, and Testa (2006) termed the **"Low Fertility Trap"**[47]. Published in the *Population and Development Review*, this hypothesis suggests a self-reinforcing downward spiral built on three interconnected mechanisms:

1. **Demographic Momentum:** Negative population momentum dictates that fewer mothers are born in each subsequent generation. This guarantees fewer total babies in the future, even if the TFR stabilizes or slightly increases, simply because the base population of fertile women has shrunk[47].

2. **Sociological Norms:** The "ideal family size" is culturally transmitted and heavily influenced by one's peer environment. As younger cohorts grow up in environments where one child or childlessness is the highly visible norm, their own baseline desires adjust downward, normalizing ultra-low fertility[47]. This has been robustly replicated in China following the One-Child Policy, where increased sibship size reduction causally lowered the ideal family size of the next generation[50].
3. **Economic Stagnation:** Following Easterlin's relative income hypothesis, aging populations lead to economic stagnation and higher tax burdens on the youth to support pension and healthcare systems. Youth experiencing worse economic conditions than their parents delay family formation further, locking the trap[47].

The Efficacy of Policy Interventions: Nordic, French, Hungarian, and East Asian Cases

Can public policy reverse these deeply entrenched cultural and economic trends? The empirical evidence suggests that pronatalist policies can act as mild "fertility-boosters," but they rarely cause structural reversals to above-replacement levels.

In a robust analysis of OECD data, Luci-Greulich and Thévenon (2013) found that comprehensive family policies—comprising paid leave, childcare subsidies, and cash transfers—can elevate cohort fertility, but the effect size is highly bounded, generally resulting in an increase of 0.2 to 0.3 children per woman[52]. French exceptionalism in Europe (maintaining a TFR near 1.8 for years) is largely attributed to this comprehensive approach, specifically their massive state investment in early, universal childcare (the *école maternelle* system) which drastically reduces the quantity-quality trade-off for working mothers.

Direct financial transfers produce mixed results. In Hungary, Gábos et al. (2009) found that aggressive family allowances boosted total fertility by a mere 0.2%[2]. In Poland, the introduction of the "Family 500+" program—a massive, untaxed monthly cash transfer—yielded a 1.5 percentage point increase in the probability of having a child in the short term. However, detailed heterogeneity analyses revealed this largely functioned as a "tempo effect" (households having children earlier than planned to secure the cash) rather than a "quantum effect" (households having more children over their entire lifetime)[2].

The most cautionary tale of policy failure resides in East Asia. South Korea has spent approximately 280 trillion won (roughly $200 billion USD) on aggressive pronatalist policies since 2006, encompassing subsidized housing for newlyweds, extended paid parental leave, and direct cash vouchers[4]. Despite this unprecedented fiscal commitment, their TFR plummeted to a global low of 0.72 in 2023[4]. The failure of Korean policy demonstrates the severe limits of cash interventions when underlying cultural and structural issues remain entirely unresolved. South Korea maintains a hyper-competitive educational environment (an extreme manifestation of the quantity-quality trade-off), severe workplace rigidity that penalizes time off, and deeply entrenched gender inequity in domestic roles, validating McDonald's Gender Equity Theory[4]. When the macro-culture remains hostile to family life, no amount of localized cash transfer can induce women to bear the resulting motherhood penalty.

Controversies and Competing Evidence

No exhaustive analysis is complete without examining internal scientific controversies and competing paradigms.

Cultural Values versus Economic Primacy: A persistent debate exists between sociologists and economists regarding the primary driver of the fertility collapse. Proponents of the Second Demographic Transition (SDT), most notably Lesthaeghe (2010), argue that the decline is fundamentally driven by post-materialist cultural values—a permanent ideological shift toward self-actualization, individual autonomy, and secularism[4]. Economists conversely argue that the decline is overwhelmingly material. They posit that if one controls for the rising cost of urban housing and the skyrocketing opportunity cost of women's wages, "post-materialist values" lose much of their explanatory power. The consensus is increasingly aligning with McDonald's framework, which bridges the two by noting that it is the *conflict* between new economic realities and old cultural expectations that crushes fertility[41].

Averages versus Individuals: A recurring analytical fallacy in public demography is applying population-level statistical averages directly to individual agents. The TFR is a mean average, leading to the colloquial concept of "1.4 children." The reality is a distinctly bimodal distribution: a large spike of permanently childless individuals, and a large spike of individuals with exactly two children, with very few having one or three[22]. Similarly, biological age curves represent cohort averages. While the statistical probability of female conception drops significantly after 35, individual physiological outcomes vary wildly; Steiner et al. (2017) proved that many women with statistically "low" ovarian reserves conceive naturally without delay[8]. Over-communicating statistical cliffs leads to unwarranted public panic and unnecessary medicalization, while under-communicating them leads to tragic cases of unintended childlessness as couples wait too long[23].

Synthesis: Evolutionary and Endocrine Perspectives

Viewing the modern life course through a combined evolutionary and endocrine lens reveals a profound, unyielding mismatch between human biology and modern institutional design. Evolution selected for a reproductive endocrine axis that peaks in the late teens and early twenties. This biological timing aligns perfectly with peak physiological resilience, maximal pelvic flexibility, and the optimal genetic integrity of both female oocytes and male spermatogonia.

Modern society, however, requires massive human-capital accumulation to survive in a knowledge economy. We implicitly demand that individuals suppress their biological imperatives during their peak fertile years to sit in university lecture halls and grind through entry-level corporate jobs. By the time society deems a couple "economically ready" to reproduce (typically their early to mid-thirties), they are fighting against the twilight of their endocrine function. Female NGF depletion accelerates rapidly, and male spermatogenesis begins accumulating the *de novo* mutations associated with advanced paternal age[6]. The result is a heavy reliance on ART, which is physically taxing, wildly expensive, and, as Habbema's models demonstrate, statistically incapable of restoring the cumulative fertility of lost years[23]. We have engineered a society that requires financial stability to breed, but withholds that stability until the biological capacity to breed is deeply compromised.

Robust Findings Summary

1. **Ovarian Reserve Depletion:** The female ovarian reserve drops to roughly 12% by age 30 and 3% by age 40, strictly limiting the natural reproductive window.
2. **Paternal Age Risks:** Advanced paternal age (>45) is a primary driver of *de novo* genetic mutations, dramatically increasing offspring risk for ASD, ADHD, and bipolar disorder.
3. **ART Limitations:** To achieve a 90% statistical certainty of a two-child family, couples must begin attempting natural conception by age 27; IVF only extends this window to age 31.
4. **The Motherhood Penalty:** The primary economic driver of delayed fertility is the earnings penalty for mothers, ranging from 20% in egalitarian nations to 60% in traditional ones like Germany.
5. **Shifting Demographics of Childlessness:** Permanent childlessness is no longer the domain of highly educated, high-status women; it is now highest among the lowest-educated men and women due to extreme economic marginalization.
6. **Quantity-Quality Trade-off:** Hyper-competitive knowledge economies severely depress fertility as parents must invest exponentially more capital into fewer children to ensure their success.
7. **Policy Ceilings:** Comprehensive family policies can increase cohort fertility, but the maximum documented effect size is highly bounded at 0.2 to 0.3 children per woman.
8. **Gender Equity Theory:** Fertility collapses to lowest-low levels in nations where women achieve public economic equality but face unequal burdens of unpaid domestic labour (e.g., South Korea).
9. **The Low Fertility Trap:** Prolonged sub-replacement fertility fundamentally alters cultural norms regarding ideal family size and creates economic stagnation, making demographic recovery exceedingly difficult.
10. **The Averages Fallacy:** While population-level biological and economic markers show strict declines, they are poor predictors of individual outcomes, creating widespread social confusion and delayed action.

Contested or Open Questions

- **The Global Sperm Decline:** Is the reported 52% decline in global sperm counts a genuine physiological crisis driven by endocrine disruptors, or an artifact of historical differences in semen analysis methodologies and counting chambers?
- **Policy Limitations in Ultra-Low Contexts:** Can any combination of financial and social policies reverse the demographic collapse in East Asia (e.g., South Korea's 0.72 TFR), or have these societies crossed an event horizon into permanent contraction?
- **Long-term Housing Market Dynamics:** Will the eventual downsizing of the aging baby boomer generation actually depress urban real estate prices as modeled by Mankiw and Weil, or will capital accumulation and rapid urbanization keep housing out of reach for the youth indefinitely?
- **The Limits of ART:** As IVF technology advances (e.g., potential future applications of in vitro gametogenesis), to what extent can technological intervention push the biological

boundaries of the Habbema models without introducing novel epigenetic risks?

Important Sources to Read in Full

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Implications for living together

Note: This section outlines pragmatic realities derived from the data, explicitly avoiding the naturalistic fallacy; the fact that humans have an evolved, rigid biological window does not mean returning to traditional, early-marriage models is morally "good," ethically required, or socially optimal.

For couples and families, the data implies an urgent need for temporal transparency and risk management. The modern assumption that career consolidation can sequentially precede family formation without consequence is a statistical gamble heavily weighted against the individual. Couples aiming for multi-child families must initiate childbearing in their late twenties, inherently overlapping with their peak career-building and capital-accumulation

years. Attempting to avoid the economic "motherhood penalty" by delaying childbirth until the late thirties frequently trades a financial penalty for a severe biological one. Couples must openly negotiate the division of domestic labour early, as the transition to parenthood is the primary site of gendered economic divergence.

For organizations and societies, the implications are fundamentally structural. If a society demands advanced education and high female labor force participation (which are net social and economic goods), it cannot simultaneously maintain rigid, traditional corporate structures and patriarchal domestic expectations without destroying its own population replacement rate. Organizations must recognize that the "ideal worker" model—demanding 60-hour weeks and unyielding availability during a worker's twenties and thirties—is demographically toxic. The solution is not a regressive push of women back into the home, which would only exacerbate the quantity-quality trade-off, but rather an aggressive restructuring of the work-life interface. This requires subsidized early childcare, genuine penalties for workplace maternal discrimination, and, crucially, the total normalization of male domestic labor and mandatory extended paternal leave to break the cultural expectation of the "second shift." Without bridging the widening chasm between our rigid biological reality and our modern economic demands, developed societies will continue to age into permanent stagnation.

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