Gender, households, children, and the city*

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Abstract

This paper studies the gender gap in the urban wage premium and its heterogeneity by couple and parental status. Using administrative data on the universe of French residents, I find that the urban wage premium is 30 to 50% larger for women than men once spatial sorting is accounted for. Contrary to expectations, this gender gap is not driven by partnered women or mothers benefiting more from density. Instead, mothers of young children experience a density penalty that nearly eliminates their additional agglomeration gains, suggesting a large role of congestion cost interacting with childcare constraints. I also find a positive effect of density on labor market participation that is stronger for women than men after controlling for sorting, and is not related to household structure.

Keywords: Agglomeration economies, urban wage premium, gender gap in earnings, households
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1 Introduction

The urban economics literature has largely established the existence of an urban wage premium: workers are more productive and earn higher wages in large cities, even after accounting for the sorting of high-skilled individuals in large urban areas. In France, Combes et al. (2008) quantify this relationship, estimating the elasticity of wages with respect to density at approximately 0.03. At the same time, despite significant progress in recent decades, the gender gap in earnings remains a persistent economic reality (Goldin, 2014). Yet the intersection of these two fundamental economic phenomena –agglomeration effects and gender disparities– remains largely unexplored. Do women and men benefit equally from the productivity advantages of dense urban environments?

In this project, I provide novel evidence on the way agglomeration economies differ by gender and household type. A key difficulty in understanding the mechanisms of differential agglomeration gains by gender is the lack of large panel datasets containing information on both labor market outcomes and household composition. I overcome this challenge by accessing a unique administrative dataset that covers the universe of French residents. By chaining it across years, I am able to track individuals and households over time, and to observe income, location, gender and household structure between 2014 and 2019. Applying a standard two-step approach to this new data, I estimate the urban wage premium by category and find that, once accounting for spatial sorting, the urban wage and participation premiums are significantly larger for women. I find that while men have an elasticity of earnings to density of approximately 0.05, this rises significantly to 0.068 for women.

Several theoretical channels could explain differential returns to density by gender. As women tend to have interrupted employment trajectories, and a smaller job search radius (Le Barbanchon et al., 2021), the better job matching in large cities could be more beneficial for them.Furthermore, if women are more likely to be tied movers (Gemici, 2007, Venator, 2023), meaning they move due to the gains of their spouses even if it is not in their direct interest, the improved job matching in large cities could help them adapt to their new residence. On the other hand, career interruptions could attenuate the effects of learning spillovers on wage growth. High congestion cost (in particular childcare and commuting) could also have a stronger netgative impact of women than on men. Finally, large cities could differ from smaller ones in their gender norms and discriminatory behavior.

Many of these mechanisms are related to household composition, either through child-related consideration or intra-household decision. In order to assess their relevance to the gender gap in urban wage premium I explore a further heterogeneity dimension and estimate the urban wage premium by gender and couple status, as well as by gender and parental status. If the household related mechanisms played an important role, we would find that the urban wage premium is larger for mothers or coupled women than for single or childless ones. I show instead that women who are in a partnership or have children do not benefit more from density. The significant gender gap in the urban wage premium is driven neither by married women, nor by mothers. Instead, I find that mothers of young children experience a density penalty which almost fully wipes off the female extra agglomeration gain. This suggests that congestion costs linked to child-related constraints wipe off potential benefits from improved matching.

This paper contributes to a large body of work on individual agglomeration gains. Starting with Glaeser and Mare (2001), many papers have documented the existence of an urban wage premium, and studied its mechanisms : Combes et al. (2008) in France; D'Costa and Overman (2014) in the UK; De la Roca and Puga (2017) in Spain. The empirical part of this literature highlights the existence of large skills sorting, explaining part of the observed wage premium: individual skills are positively correlated to city-size. However, sorting does not explain all of the city size premium, and the literature has shown that there are still gains from density even when sorting is accounted for. Few articles however have explored the heterogeneity of agglomeration gains for different types of worker. Carlsen et al. (2016) estimate the urban wage premium by education level in Norway, and find that college-educated workers have a higher return to working in cities. Another example is Ananat et al. (2018) who show that black workers in the US receive a significantly lower employment density premia than white workers. More recently, Le Roux (2025) shows that returns to density in South Africa are significantly higher for high-income than low-income individuals.

A small set of articles have studied how this wage premium varies by gender. Both Phimister (2005) and Hirsch et al. (2013) find evidence of a small urban participation premium for women but are only able to compare urban and rural women. More recently D'Costa (2024) also estimates the impact of working in cities –defined by opposition to rural areas– on men and women's wages, and finds that before 2008 the urban wage premium for women was twice that of men, but that this difference disappeared after the 2008 crisis. In a different context, Le Roux (2025) finds no difference in the gains from density by gender in South Africa. The closest article to my work is and Elass et al. (2024), who use a similar two-step approach on another French dataset to estimate the impact of urban density on the gender wage gap. They also find that that women benefit more than men from urban density, and after decomposing this gap, they conclude that occupational segregation plays a large part in explaining the difference, followed by childcare and commute constraints. I complement their research by exploring another dimension of heterogeneity: the role of household structure, in particular couple status and presence of children.

While various studies document heterogeneity in agglomeration gains by gender, there is little literature on the mechanisms of these differential gains. In this paper, I explore the particular dimension of household structure: as men and women have become more and more similar in their productive characteristics, household-level factors become more important to explain the remaining gender gap. The recent literature on the gender gap in earnings and its sources underlines the importance of children and intra-household specialization in explaining the persistence of this gap (Goldin, 2014, Angelov et al., 2016, Kleven et al., 2019, Cortés and Pan, 2023, Goldin, 2024). Within-couple specialization, with one member (often the man) focusing on paid work and the other taking on more of the childrearing and domestic work, may lead women to choose jobs which offer more flexibility but lower wages: part-time (Manning & Petrongolo, 2008), requiring less presenteeism (Azmat et al., 2022), with less commute (Le Barbanchon et al., 2021)... The role of household factors in agglomeration economies has been put forward by the "power couples" literature dating back to Costa and Kahn (2000), which argues that returns to larger cities may be larger for (highly-educated) couples than other households. This paper is the first to systematically study the role of intra-household factors in differential agglomeration gains by gender.

In a last section I contribute to a small strand of literature which studies geographical disparities in labor market participation by women, dating back to Odland and Ellis (1998). Black et al. (2014) document large and persistent variation in female participation across US cities, with women in large cities being less likely to work. Similarly, Moreno-Maldonado (2022) finds that women with children are less likely to work when located in big cities. Both papers argue that this is driven by differences in commuting and childcare cost, which create an incentive for intra-household specialization: one spouse working long hours while the other stays out of the labor market. I contribute to this literature by showing that accounting for individual fixed effects in estimation of the participation gap reverses the findings: once sorting is accounted for, I find a positive effect of density on participation which is even larger for women than men.

The rest of this article is organised as follows. In section 2 I expand on the theoretical mechanisms which could explain a gender gap in agglomeration economies. Section 3 details the data used in the analysis, the sample, and the definition of main variables. Section 4 explains the empirical approach to estimate the urban wage premium by group, and section 5 discusses the results, while section 6 focuses on the urban participation premium. Finally, section 7 concludes.

2 Theoretical mechanisms

Agglomeration economies encompass various mechanisms through which larger cities positively affect individual and firm income (Combes & Gobillon, 2015). Since Duranton and Puga (2004), those theoretical channels are often classified into three categories: matching, learning and sharing. *Matching* describes how large cities boost productivity and wages by improving both match quality between workers and firms and the probability of finding a match. *Learning* (defined broadly to encompass knowledge acquisition, diffusion and creation) occurs more easily in large cities through firm-to-firm and worker-to-worker interactions. Finally, *sharing* includes multiple dimensions: access to more inputs ("gains from variety"), risk sharing, industry specialization, and access to local indivisible goods and facilities.

These mechanisms suggest several pathways through which the urban wage premium might differ by gender.

The matching channel is particularly relevant for women, in particular mothers, who experience more frequent career interruptions. Denser labor markets could provide them with improved job-matching opportunities that mitigate these disruptions. Furthermore, large cities may offset women's typically smaller job search radius (Le Barbanchon et al., 2021) by offering more employment options within accessible distances. Furthermore, since women are more likely to be "tied-movers" –meaning that households location decisions often prioritize male partners' careers (Feuillade, 2025; Mincer, 1978; Tenn, 2010)–large cities could significantly reduce the career penalty women face by providing more diverse employment opportunities. Following a spouse to a large city rather than a small one would improve expected job quality and reduce search time. Overall the larger array of positions and better matching offered in large cities could help offset the constraints faced by women in their job search behavior.

The sharing mechanism may similarly benefit women differently than men. Access to public goods in dense areas, such as childcare facilities and public transportation, could especially advantage women with children or those in dual-earner households. Better transportation infrastructure could alleviate the within-city dual-location problem faced by couples and expand women's job search radius.

On the other hand, the congestion costs of large cities, which may induce longer commuting times and higher housing and childcare cost could impact women's (and in particular mother's) incentive to work (Moreno-Maldonado, 2022).

These mechanisms all relate to intra-household decisions and constraints. If these mechanisms predominantly operate through household constraints and childcare responsibilities, we would expect gender differences in agglomeration benefits to be concentrated among partnered women and mothers, while single, childless women –who face neither child-related interruptions nor dual-career constraints– should exhibit patterns more similar to men.

Instead, I find a gender-specific gain from agglomeration that benefits all women, including those who are single and childless, suggesting mechanisms beyond household composition are at play. I find no significant heterogeneity by couple status, which could either mean that the household-related channel are not at play, or that the positive effects of matching and sharing and the negative congestion effects approximately offset each other for coupled women. However, I show that mothers of young children experience a substantial negative density effect that eliminates their gender-specific agglomeration benefit, indicating the dominant role of congestion costs for this particular group.

A remaining question is what might explain the presence of a gender gap in agglomeration benefits for single and childless women. Occupational segregation could offer one potential explanation. Papageorgiou (2022) argue that the higher number of available occupations in large cities is a key explanation for the existence of an urban wage premium. Since smaller cities have fewer occupational options, gender-based occupational segregation may be more pronounced in these areas. Given that male-dominated occupations generally exhibit higher wages, this mechanism could generate gendered returns to density. Elass et al. (2024) confirm the importance of this channel, though they find that occupational differences alone cannot fully explain the gender gap in urban wage premiums.

Finally, gender heterogeneity in the urban wage premium could also arise from lower gender-based discrimination. While this is not something I can measure, it is plausible that large cities exhibit more egalitarian gender views and less discriminatory behavior due to local cultural norms or to the sorting of individuals with less discriminatory attitudes. This could create an additional benefit for women in dense labor markets that operates independently of household composition or occupational structure.

3 Data and summary statistics

In this paper, I leverage the Housing and Individual Demographic Files (FIDELI), an administrative dataset covering the universe of French residents between 2014 and 2019. This dataset integrates information across three levels –individuals, households, and housing units– all linkable through unique identifiers.

At the individual level, FIDELI provides basic demographic characteristics (age, gender, birthplace) and detailed income information. While it lacks specific job variables (occupation, hours, industry), it breaks down pre-tax annual income by source (wages, pensions, benefits...). This allows me to construct a comprehensive measure of annual labor income that includes both wages and earnings from independent professions (agricultural, industrial, commercial, or non-commercial). I also use unemployment income data to identify individuals experiencing unemployment within a given year.

A key advantage of FIDELI is the precise geocoding of each individual's address on January 1st of each year. Additionally, the dataset's tax-source origins enable direct identification of fiscal households, allowing me to determine which individuals are married or in civil unions. This measure of couples however misses individuals who are simply living together without any legal status, and cannot file taxes together. To capture those unmarried couples, I expand my definition to include all pairs of adults who live in the same house or flat, with no other adult present. To address potential misclassification concerns, I replicate all results using two alternative, more restrictive definitions: tax-filing couples only, and cohabiting adult pairs with at least one minor child in the household. Results in Appendix A.2 confirm that my findings remain robust across these alternative specifications.

The spatial unit of interest in this analysis are Urban Areas, as defined in 2010 by the National Institute of Statistics (INSEE). Urban Areas are large units defined to encompass an urban core containing at least 10,000 jobs [1] and surrounding municipalities in which at least 40% of the working population is employed within the urban area, in a recursive approach. My estimation of the urban wage premium will rely on within-individual and across-urban areas variation in annual income. However, since I only observe individuals' location at the beginning of each calendar year, I cannot attribute their income to the city it is earned in when people move during the year. I therefore exclude these transition years from my analysis.

My final sample consists of individuals aged 25-60 living in urban areas within mainland France, excluding Corsica and overseas territories. This leaves me with a panel of 19,825,498 people, and over 100 million observations.

Table 1 provides some descriptive statistics of the main variables for men and women separately. Because of the very high number of observations, all the difference are statistically significant. Yet the male and female sample are very similar in terms of demographic characteristics: age, couple status, presence of children, number of children (conditional on having at least one). The largest differences are observed for labor market outcomes: women in my sample earn 30% lower annual labor income than men. They are also more likely to be unemployed or to not be receiving any labor income.

Importantly, men and women appear to be quite similar in their mobility. Women are 7% less likely than men to move over the period. Conditional on moving they appear to be about as likely as men to move towards a smaller (resp. larger) city. They live in cities that are approximately the same size and are as likely to be living in Paris.

[1] In their 2010 definitions, INSEE provides three categories of urban areas, with the smallest ones built around a core of 1,500 or 5,000 jobs. As those are small cities, with few variation in density, I exclude them from the analysis and focus instead on relatively large urban areas. Those correspond to 93% of urban area residents

Table 1: Descriptive statistics by gender

	Male	Female	Difference	T-Statistic
Age	43.157	43.189	0.328***	179.010
Has child	0.494	0.516	−0.022***	−219.510
Number children (conditional)	1.833	1.789	0.043***	176.480
Married	0.576	0.565	0.011***	114.110
Married or cohabiting	0.715	0.688	0.026***	287.580
Married or cohab w/ child	0.662	0.643	0.019***	200.700
Labor income	30,855	21,289	9,566***	1,418.290
Receives UI	0.136	0.151	−0.015***	−204.010
Receives labor income	0.949	0.917	0.033***	642.510
Mobility	0.07	0.065	0.005***	90.410
Number of moves	0.074	0.069	0.005***	82.640
Number of moves (conditional)	1.151	1.139	0.012***	39.130
Moves to smaller city (conditional)	0.621	0.628	−0.007***	−16.140
Moves to larger city (conditional)	0.484	0.468	0.017***	38.710
City population	3,677,053	3,772,937	−45,884***	−44.890
Lives in Paris	0.264	0.268	−0.004***	−44.780
Number of years in panel	5.591	5.641	−0.050***	−263.820
Number of observations	48,484,931	53,602,445		

Note: This table is computed from Fideli data. The sample is made of individuals living in an urban area in mainland France, aged 25-60. * $p < 0.1$, ** $p < 0.05$, $^{***}p < 0.01$

4 Estimating the urban wage premium: the two-step approach

The standard methods to estimate the density wage premium in the urban economics literature is a two-step approach developed by Combes et al. (2008). This method first estimates individual wages using a model with individual and city fixed effects, then regresses the estimated city effects on city size to determine the elasticity of wages to city size. I adapt this method to estimate gender-specific elasticities as follows.

First I run the regression described in equation (1):

$$y_{i,t} = \theta_i + \mathbf{X_{i,t}}\gamma_{G(i,t)} + \beta_{c(i,t),G(i,t),t} + \varepsilon_{it} \tag{1}$$

In this equation the outcome variable $y_{i,t}$ represents to annual labor income. θ_i is an individual fixed effect, included to control for the sorting of individuals across cities along unobserved characteristics. The vector X_{it} contains individual characteristics, which in practice consist of age squared interacted with gender. My coefficient of interest, $\beta_{c(i,t),G(i,t),t}$ is a fixed effect for each urban area - group - year combination. Depending on the specification, the group $G(i,t)$ corresponds to a combination of gender $g(i)$, marital or cohabiting status $m(i,t)$, and parental status $p(i,t)$.

In a second step, I regress the estimated $\widehat{\beta}_{c,G,t}$ on group indicators interacted with city size variables, as well as year fixed effects. Equation 2 formalizes the second step regression for the simple case when groups are defined based on gender only, using population density ($d_{c,t}$) as a single measure of city size.

$$\widehat{\beta}_{c,g,t} = \alpha + \eta.\mathbb{1}_g + \phi.\log d_{c,t} + \delta.\mathbb{1}_g.\log d_{c,t} + \lambda_t + \nu_{c,g,t} \tag{2}$$

Population density is a typical measure of city size since the seminal paper by Ciccone and Hall (1996). However, while it provides insight into a city's "compactness", it represents only one dimension of city size –a highly populated city could have low density but large surface area. To account for this, I also introduce land area (interacted with group indicators) in the second stage regression. When both variables are included, density represents the intensive margin of agglomeration: an increase in population for a given city surface. Land area on the other hand captures the extensive margin of agglomeration: an increase in the city footprint holding constant the overall density.

In equation 2 density and area are centered around the average for men. This allows η to be interpreted as the difference in city fixed effects between men and women living in the average city *of men*. The coefficient ϕ captures the effect of a change in density relative to men's average city, while δ, my main coefficient of interest, represents the gender gap in the urban wage premium –specifically how women's wages respond differently to city density compared to men's. In cases where groups are defined as the interaction of gender with couple and/or parenthood, the city size variables are centered around single and/or childless men.

When estimating equation 2, I weight the regression by the number of observations in each group from the first stage. This allows to interpret these results from the perspective of individuals, as this equation becomes consistent with a model in which the city-group-year effects $\beta_{c(i,t),G(i,t),t}$ in equation 1 would be replaced by their expression in equation 2. It also has the advantage of putting more weight on the most precisely estimated city-group-year effects. The standard errors in this second step are clustered at the city-year level, as there is no variation in density and area within each city-year group.

A common concern when estimating equation 2, is that these regressions may suffer from a series of endogeneity bias, as wages and city size are jointly determined when households and firms choose where to locate. For instance, high productivity and wages could encourage migration to a city, leading to an issue of reverse causality. Omitted local variables could also be affecting both wages and population of a city. To address those concernss, I use a standard strategy and instrument cities' density and area with a set of historical city characteristics and geological features, following Ciccone and Hall (1996) and Combes et al. (2010). More precisely, I use historical values of population density in 1793, 1800, 1836, and 1856, obtained from historical censuses' municipality-level population count. These instruments should be highly correlated to current density, thanks to the strong persistence of urban infrastructure. Yet, given the large changes in production function in the last 150 years, the unobserved local determinants of city size should no longer be the same than in the past, meaning that these instruments should satisfy the exclusion restriction. Geological characteristics[2] should also have a good predictive power as soil fertility determined the way that population was distributed in the past, when agriculture was more important, but we do not expect it to be correlated to productivity and wages in modern cities.

5 Gaps in the urban wage premium by gender and marital status

5.1 Results by gender

Table 2 presents the results of the two-step approach described in the previous section, in which fixed effects are computed by gender city and year combination. The corresponding first stage results can be found in Table A1 in Appendix. Columns (1) and (2) correspond to the estimation of equation 2, while columns (3) and (4) instrument density and land area with historical and geological variables.

Results in column (1) indicate that women who work benefit significantly more from city density than men: the elasticity of their wages with respect to density is around 50% higher than men's. Living in a city with double the density leads to an increase in average wage of 6.95% for men, and 10.4% for women[3]. By introducing land area in columns (2), the elasticity of wage to density reduces by half for both men and women, indicating that part of the density premium in column (1) was capturing the fact that city with higher density also have higher population on average. By controlling for land area, we are now able to disentangle those two dimensions. Interestingly, this adjustment affect men and women in the same way, approximately halving the elasticity of wages to density for both. This suggests that the intensive and extensive margin of agglomeration have around the same relative importance for men and women.

[2] I use as geological characteristics the proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content

[3] If two cities are such that $dens_c = 2 \times dens_{c'}$, it means that $\log(w_c/w_{c'}) = \phi \log(dens_c/dens_{c'}) = \phi \log 2$, with ϕ the coefficient on $\log dens$. So $w_c/w_{c'} = 2^{\phi}$. This means that a doubling of density is associated with a $(2^{\delta} - 1) \times 100\%$ increase in wage.

Table 2: The density earnings premium by gender

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.098***	0.050***	0.091***	0.016***
	(0.014)	(0.005)	(0.016)	(0.005)
Female × Density centered	0.049***	0.018***	0.059***	0.025***
	(0.010)	(0.005)	(0.011)	(0.006)
Area centered		0.040***		0.069***
		(0.004)		(0.005)
Female × Area centered		0.025***		0.029***
		(0.005)		(0.007)
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.965	0.977	0.958	0.968
KPW F-Stat			206.316	7.418
N	2736	2736	2712	2712

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x year group in 1st stage. The dependent variable is the urban area x gender x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

In columns (3) and (4) I report the results of the regression when instrumenting both density and area with historical and geological variables. When introducing only density in the second stage equation in columns (3) I obtain estimates which are very similar to column (1), confirming the common finding of the literature that the potential endogeneity biases are not large. In column (4) however the estimated coefficients on density and land area are no longer so stable. This is likely caused by lack of power in my instruments, due to the strong correlation between a city's density and its land area.

It is worth noting in interpreting the results of Table 2 that the outcome variable is *annual* labor income. This means that I am capturing many potential mechanisms, which I cannot always observe directly in my data. In particular I am not able to measure hourly or daily wage, which would be a better measure of productivity. An increase in annual income in my data could be caused either by an increased wage rate or by an increase in the number of hours worked. Given the higher prevalence of part-time work among women, this may be a highly relevant channel. It is plausible that part of the agglomeration premium may occur through an increase in the probability of working full time, conditional on being employed.

5.2 The role of household structure

As discussed in section 2, many of the potential mechanisms for this gender gap in the urban wage premium stem from joint household considerations, and/or from childcare considerations. If these mechanisms are indeed important ones, we should find significant heterogeneity in the urban wage for married women or mothers.

5.2.1 Couples

In order to test whether coupled women benefit more than single women from agglomeration, I reproduce I reproduce the two-step approach described in section 4, with the a city-group-year effect $\beta_{c,G,t}$ defined by gender and couple status.

Table 3 shows the result of the corresponding second stage estimation. As before, the estimated urban wage premium in columns (1) and (2) is around 50% larger for women than for men. When controlling for land area in column (2), I find a 0.049 elasticity of annual income to density for single men, which rises to 0.069 for single women. This is almost identical to the results of Table 2, where I found an elasticity of 5.0% for men and 6.8% for women. This is a first indication that couple status may not matter much in explaining the gender gap in the urban wage premium. If the gendered gains from agglomeration happened exclusively through household-related channels, we should not find any difference between single men and single women, but rather a positive effect of the interaction of gender, couple and city size.

Instead, this triple interaction is negative for both density and land area implying that if anything cohabiting women gain less than single ones from cities' density. However it is worth noting that while this triple interaction is statistically significant in column (2), it is of much smaller magnitude than the interaction of gender with city size. I also find no differential effect of city size on earnings for cohabiting men. Using the instrumental variable approach in columns (3) and (4) does not affect these results.

I reproduce this estimation using alternative definitions of couples in Table A2 (married or civil union) and A3 (married, civil union, or cohabiting *in the presence of a minor child*). In both cases I find very similar results: a strong and significant gender gap in the urban wage premium, and a small and negative coefficient on the intersection of gender, couple status and city size although it is more strongly statistically significant when using those two definitions.

Children

Could the real driver of the observed gender heterogeneity in the density earnings premium be motherhood? As discussed previously, the disruption that children create in women's career (Cortés & Pan, 2023) may affect the way they can take advantage of agglomeration economies. The direction of this effect is however unclear: while matching and sharing mechanisms would suggest a positive impact, this could be counteracted by congestion costs. Furthermore such a differential effect of city size on mothers should vary depending on the age of the youngest child. Mothers of younger children, who face stronger childcare constraints and may have had more recent career interruptions, might be more likely to have different returns to city size.

In order to test these hypothesis I reproduce the analysis including in the first stage regression city year effects $\beta_{c,G,t}$ which are defined by gender and parental status. I repeat the estimation with three different age thresholds, related to average age of entry in the different school levels in France. I define parents alternatively as those who have a minor child (under 18), a child under 10 years old (corresponding to children pre-middle school entry); under 6 years old (pre-primary school); and under 3 years old (pre-kindergarten). The detailed results can be found in Appendix, in Tables A4, A5, A6, and A7. For comparability purposes, Figure 1 displays graphically the coefficients from the the specification in which the $\widehat{\beta}_{c,G,t}$ are regressed on both density and land area, with no instrumental variables.

As before, I find a large gender gap in the wage premium, with women's gains from density and area being around 50% larger than for men. Depending on the age threshold considered, the overall elasticity of earnings to density (when controlling for land area) is estimated to be between 6.7% and 7.4%, which remains similar to the 6.8% for women overall found in Table 2. This indicates that the overall gender gap in agglomeration gains is not driven specifically by children-related mechanisms.

Instead I find significant negative coefficients on the interaction of gender, parenthood and density, which suggests that agglomeration may be harmful to mothers' labor income. When focusing on mothers of children under three (Table A7), the coefficient of -0.026 on the triple interaction almost fully cancels out the extra gain from density accrued by women. For mothers of children under six (Table A6) and ten (Table A5), the triple interaction only reduces by half the gender gap in the density premium, while for mothers of minor children it is no longer statistically significant.

This pattern is consistent with congestion in large cities having a large negative impact on mothers income: high commuting and childcare costs would be particularly harmful to mothers of young children who face more child-related constraints than those of older children.

If these congestion costs are indeed an important factor, removing land area from the regression should decrease the magnitude of the triple interaction coefficient on density. When both population density and land area are included in the regression (Column 2), we capture a scenario where cities cannot expand geographically as population increases. In this case, greater density leads to more severe congestion effects –housing prices rise and commuting becomes more difficult as people compete for limited space.

In contrast, when only density is controlled for (Column 1), the model implicitly allows for city expansion, which would attenuate congestion effects. The empirical results support this interpretation: the triple interaction coefficient (density $\times$ female $\times$ young child) is consistently more negative when land area is controlled for than when only density is included. This larger negative effect when land area is fixed provides additional evidence that congestion costs are a key mechanism through which density reduces the earnings of mothers with young children.

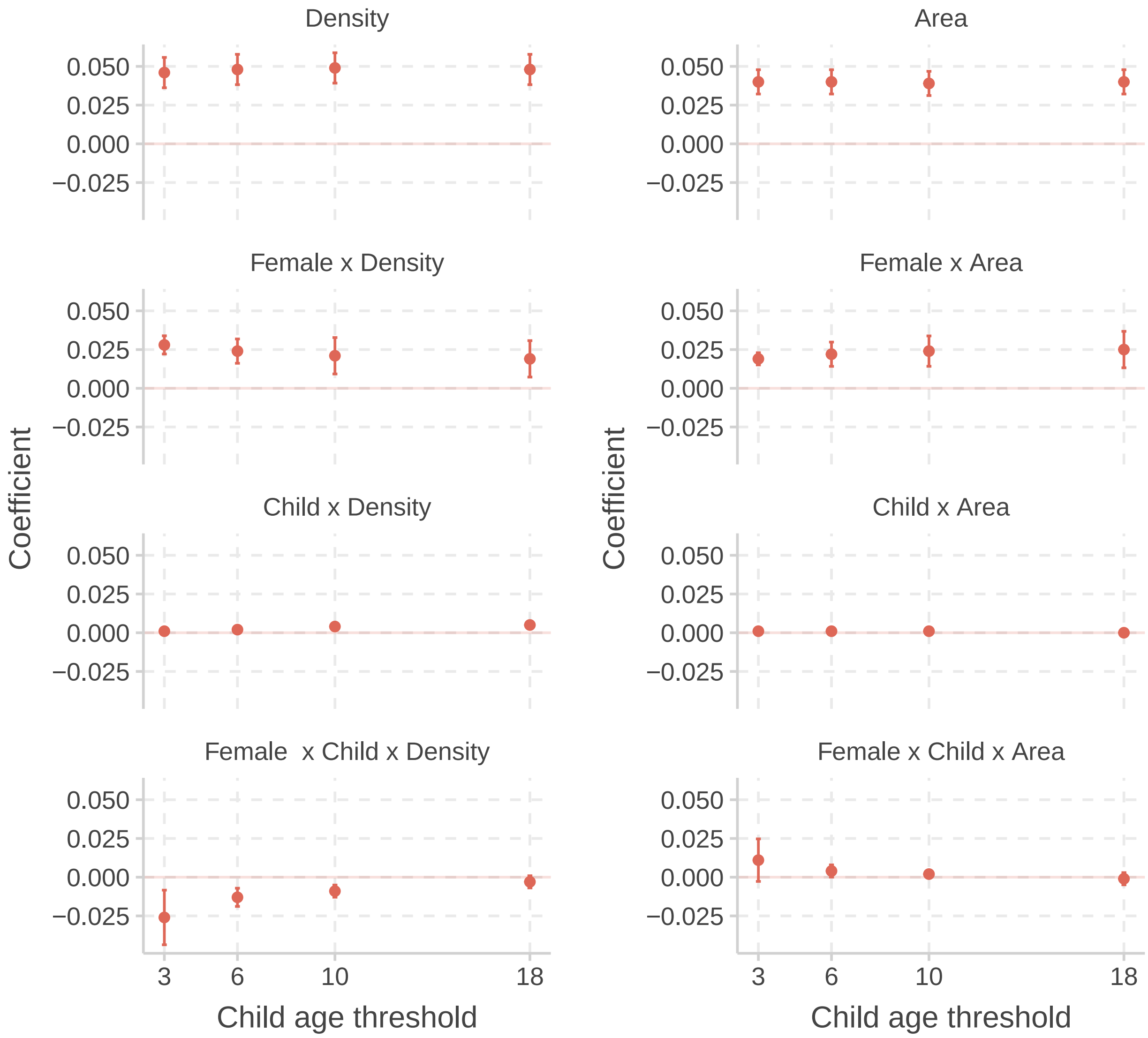
Overall, these results imply that the motherhood-related matching mechanisms described in section 2 are not at the heart of the gender gap in the urban wage premium. Instead, the negative effect of congestion seems to be harming mothers of young children, who benefit less than other women from agglomeration gains. Interestingly, men with young children do not face the same density penalty: the interaction of density and parenthood is consistently positive, although very small. This could be consistent with intra-household specialization: while the combination of congestion costs and childcare constraints hinder women's income in large cities, their partners might compensate for this relative loss.

Table 3: The density earnings premium, by gender and cohabiting status

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.100***	0.049***	0.094***	0.014**
	(0.014)	(0.005)	(0.016)	(0.005)
Female × Density centered	0.051***	0.020***	0.060***	0.026***
	(0.010)	(0.005)	(0.011)	(0.006)
Cohabiting × Density centered	-0.003***	0.001	-0.004***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Cohabiting × Female	-0.002	-0.002*	-0.003	-0.001
× Density centered	(0.002)	(0.001)	(0.003)	(0.001)
Area centered		0.041***		0.071***
		(0.004)		(0.004)
Female × Area centered		0.024***		0.028***
		(0.005)		(0.007)
Cohabiting × Area centered		-0.001***		-0.003***
		(0.000)		(0.001)
Cohabiting × Female		0.001		0.001
× Area centered		(0.001)		(0.002)
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.963	0.976	0.955	0.966
KPW F-Stat			164.7	9.193
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x couple x year group in 1st stage. The dependent variable is the urban area x gender x couple x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of single men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

Figure 1: Coefficients on group characteristics interacted with city size, by child age threshold - density earnings premium



Note: This figure is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Bars represent 95% confidence interval computed from robust standard errors, clustered at the urban area × year level. The regressions are run separately for each age threshold. Regressions are weighted by the size of each city x gender x parenthood x year group in 1st stage. The dependent variable is the urban area x gender x parenthood x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of childless men.

6 A participation premium?

So far, in section 5, I used log annual labor income as my main outcome variable, which automatically excluded non-working individuals from my estimations. This approach ignored the extensive margin of labor supply: participation in paid employment. However, the agglomeration mechanisms described in section 2 may differentially impact men's and women's participation rates.

The matching channels could directly affect women's employment probability: finding a job after career interruptions or when relocating with a partner may be more difficult in smaller cities. High living costs in large cities might also drive women to work to supplement household income. Conversely, the substantial congestion costs in large cities could act as a fixed cost of working, potentially discouraging some women from labor market participation altogether (Black et al., 2014).

To investigate this question, I replicate my two-step empirical approach with a new outcome variable: an indicator for earning positive labor income during the year. Table 4, columns (1) and (2), present results where first-stage city-year effects are defined by gender only.

I find a substantial positive effect of agglomeration on employment probability. Doubling city density (allowing for land area to adjust) is associated with a 0.009 percentage point increase in the probability of earning labor income for men and a 0.018 percentage point increase for women.[4] Including land area in column (2) reduces these magnitudes, consistent with congestion costs counterbalancing agglomeration's positive effects: when the city fringe cannot adjust, increasing population density becomes less beneficial.

Columns (3) and (4) present results where first-stage city-year effects are defined by both gender and couple (cohabiting) status. Introducing this additional heterogeneity dimension barely affects the previously estimated coefficients on the city size and gender interaction. The triple interaction estimates are precisely estimated zeros, indicating this employment density premium is not driven by partnered women.

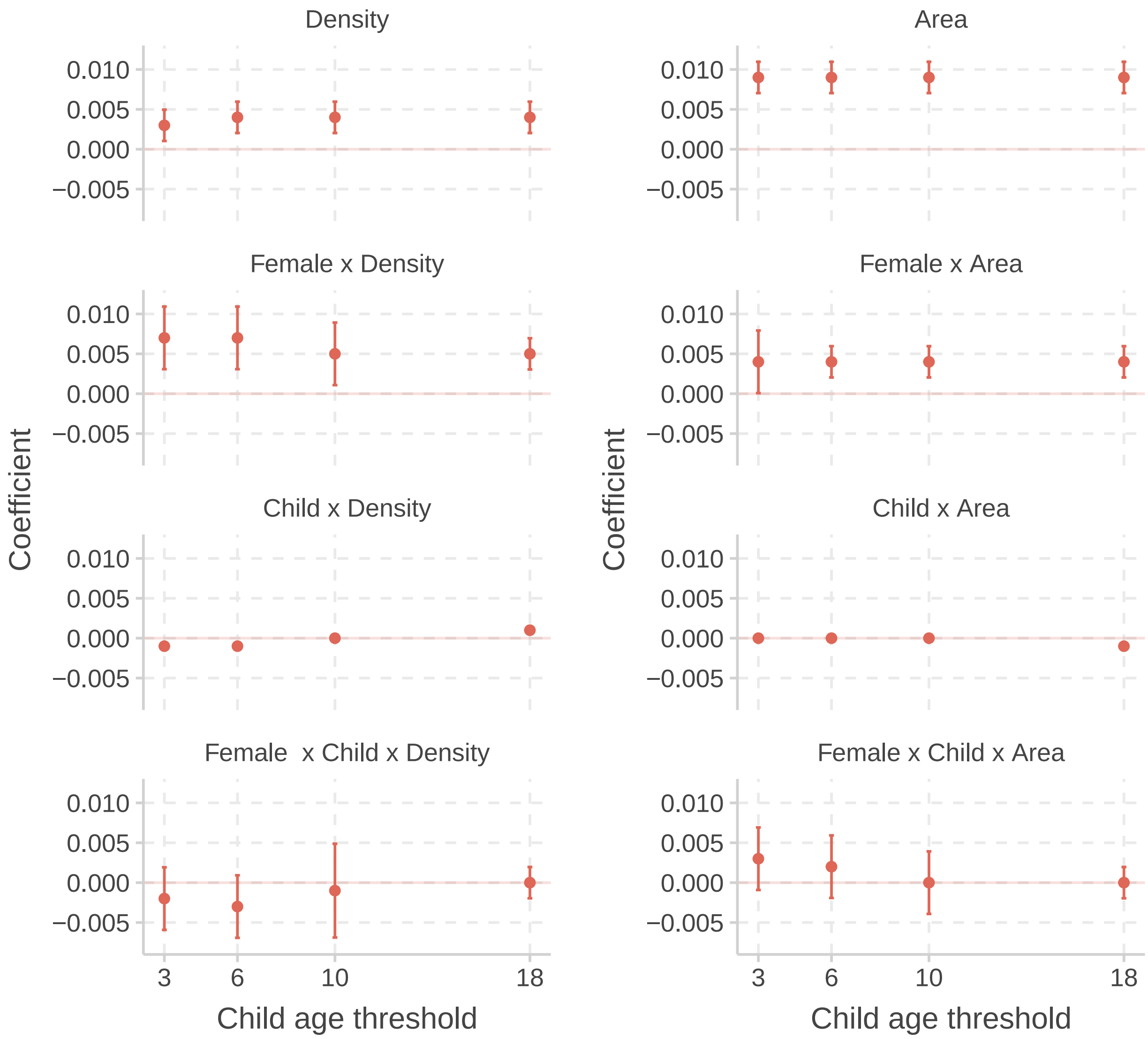
However, parenthood likely represents a more relevant heterogeneity dimension than cohabitation status, as career interruptions typically relate more to having children than living with a partner.

To allow for this possibility, I reproduce the estimation with city-year-parenthood fixed effects, defined using the same threshold as previously: 18, 10, 6 and 3. In Figure 2 I plot the coefficients obtained from a regression of these effects on cities' density and area. I find again a large effect of agglomeration on employment, with a significant gender gap: women benefit at least twice as much as men from density in terms of employment. The coefficient on the gender-parenthood-agglomeration variables is not statistically significant. This indicates that the female employment density premium is not primarily

[4]Denote p the probability of an individual earning some labor income. If two cities are such that $dens_c = 2 \times dens_{c'}$, and $p_c = \phi dens_c$, it means that $p_c - p_{c'} = \phi \log(dens_c / dens_{c'}) = \phi \log 2$.

driven by mothers, contrary to what theory might suggest about career interruptions. Instead, the employment benefits of density appear to apply broadly across women's demographic groups.

Figure 2: Coefficients on group characteristics interacted with city size, by child age threshold, density employment premium



Note: This figure is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Bars represent 95% confidence interval computed from robust standard errors, clustered at the urban area × year level. The regressions are run separately for each age threshold. Regressions are weighted by the size of each city x gender x parenthood x year group in 1st stage. The dependent variable is the urban area x gender x parenthood x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of childless men.

Table 4: The employment density premium: second stage results by gender and couple status

	By gender		By gender & couple	
	$\widehat{\beta}_{c,G,t}$ from Work income > 0			
	(1)	(2)	(3)	(4)
Density centered	0.014***	0.003**	0.015***	0.003**
	(0.003)	(0.001)	(0.003)	(0.001)
Female × Density centered	0.012***	0.007***	0.012***	0.007***
	(0.004)	(0.003)	(0.004)	(0.002)
Cohabiting × Density centered			-0.001***	-0.000
			(0.000)	(0.000)
Cohabiting × Female × Density centered			0.000	0.000
			(0.002)	(0.001)
Area centered		0.009***		0.009***
		(0.001)		(0.001)
Female × Area centered		0.004*		0.004**
		(0.005)		(0.002)
Cohabiting × Area centered				-0.001***
				(0.000)
Cohabiting × Female × Area centered				0.000
				(0.001)
Year FE	Yes	Yes	Yes	Yes
R^2	0.948	0.963	0.944	0.960
N	2736	2736	5472	5472

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each group x year combination in the 1st stage. The dependent variable in columns (1) and (2) is the group x year fixed effect obtained from equation 1, in which the outcome variable was a dummy variable for having earned some labor income during the year. In columns (1) and (2) groups refer to city x gender; in columns (3) and (4) to city x gender x couple. Density and area are in logarithm, centered around the mean of men in columns (1) and (2), single men in columns (3) and (4).

7 Conclusion

This paper documents significant gender differences in urban agglomeration economies. Using French administrative data and controlling for spatial sorting through a standard two-steps approach, I find that women experience a substantially larger urban wage premium than men, with elasticities of earnings to density of 0.068 and 0.05 respectively. Contrary to what several theoretical mechanisms might predict, neither partnership status nor motherhood in general drives these differential returns to density. On the contrary, mothers of young children appear to experience negative density effects that counteract the additional benefits women typically receive from urban agglomeration. This suggests that specific constraints related to childcare and urban congestion disproportionately affect mothers in high-density areas, effectively neutralizing the improved job matching opportunities that cities might otherwise offer them.

These findings suggest that urban density potentially offers a mechanism to reduce the gender wage gap, yet this potential is constrained by the disproportionate effect of children on women's labor market outcomes.

Additionally, I find a positive relationship between urban density and labor market participation after controlling for individual fixed effects, countering previous findings in the literature that did not account for sorting. This urban participation premium is more pronounced for women than men, but is again not driven specifically by partnered women nor mothers.

Overall, the fact that the extra gains to density for women are not explained by intra-household mechanisms or the presence of children suggests that other factors –possibly including occupation, hours worked, public sector employment, or discrimination– may play more significant roles in explaining why women benefit more from urban agglomeration. In the future it would be interesting to decompose this gender gap into its different margins, using alternative data. By estimating the density premium separately for daily income and hours worked, rather than annual income alone, we would gain a better understanding of the mechanisms driving gender differences in agglomeration gains. Another dimension that would be worth exploring is the role of occupations: is it the case that women work in occupations for which the gains of density are higher? This should all be possible using the French matched-employer employee data.

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Gender, households, children, and the city

Online Appendix

Mylène Feuillade

A Additional tables and figures

A.1 First stage results

Table A1: First stage regressions results

	Fixed-effects defined by:					
	Gender	Gender × Couple	Gender × Child <3	Gender × Child <6	Gender × Child <10	Gender × Child <18
	(1)	(2)	(3)	(4)	(5)	(6)
Age squared	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age squared × Female	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.773	0.773	0.774	0.774	0.773	0.773
Adj. R^2	0.718	0.718	0.719	0.718	0.718	0.718
N	88,343,901	88,343,901	88,343,901	88,343,901	88,343,901	88,343,901

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Couples are restricted to people who are married or in a civil union. The dependent variable is the log of annual labor income.

A.2 Alternative couple definitions

Table A2: Second-stage FE regression results, by gender and marital status

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.097***	0.047***	0.091***	0.013***
	(0.014)	(0.005)	(0.016)	(0.005)
Female × Density centered	0.052***	0.021***	0.061***	0.026***
	(0.010)	(0.005)	(0.011)	(0.006)
Married × Density centered	0.001	0.004***	-0.000	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Married × Female	-0.007***	-0.004**	-0.006**	-0.002
× Density centered	(0.002)	(0.002)	(0.003)	(0.001)
Area centered		0.041***		0.070***
		(0.004)		(0.004)
Female × Area centered		0.025***		0.029***
		(0.005)		(0.006)
Married × Area centered		-0.001***		-0.003***
		(0.000)		(0.001)
Married × Female		-0.001		-0.001
× Area centered		(0.001)		(0.002)
Female; Married; Married × Female	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.960	0.974	0.951	0.962
KPW F-Stat			174.8	9.355
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Couples are restricted to people who are married or in a civil union. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x couple x year group in 1st stage. The dependent variable is the urban area x gender x couple x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of single men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

Table A3: Second-stage FE regression results, by gender and cohabiting status (w/ children)

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.099***	0.048***	0.094***	0.013**
	(0.010)	(0.005)	(0.016)	(0.006)
Female × Density centered	0.052***	0.021***	0.060***	0.027***
	(0.010)	(0.005)	(0.011)	(0.006)
Cohabiting w/ child × Density centered	-0.002**	0.002**	-0.003***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Cohabiting w/child × Female × Density centered	-0.005*	-0.004**	-0.005*	-0.004***
	(0.003)	(0.002)	(0.003)	(0.001)
Area centered		0.041***		0.071***
		(0.004)		(0.004)
Female × Area centered		0.024***		0.028***
		(0.005)		(0.006)
Cohabiting w/child × Area centered		-0.001**		-0.003***
		(0.000)		(0.001)
Cohabiting w/child × Female × Area centered		0.001		0.001
		(0.001)		(0.002)
Female; Cohabiting w/child; Interactions	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.960	0.974	0.950	0.962
KPW F-Stat			163.9	8.656
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. Couples are restricted to people who are married, in a civil union, or living in a shared housing with one other adult and at least one minor child. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x couple x year group in 1st stage. The dependent variable is the urban area x gender x couple x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of single men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

A.3 Tables by gender and parenthood status

Table A4: Second-stage FE regression results, by gender and parental status (minor child)

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.096***	0.048***	0.090***	0.014**
	(0.015)	(0.005)	(0.016)	(0.005)
Female × Density centered	0.049***	0.019***	0.060***	0.028***
	(0.011)	(0.006)	(0.013)	(0.007)
Child < 18 × Density centered	0.005***	0.005***	0.004***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Child < 18 × Female	-0.005*	-0.003	-0.006*	-0.007***
× Density centered	(0.003)	(0.002)	(0.003)	(0.002)
Area centered		0.040***		0.069***
		(0.004)		(0.005)
Female × Area centered		0.025***		0.027***
		(0.006)		(0.008)
Child < 18 × Area centered		0.000		-0.001
		(0.000)		(0.001)
Child < 18 × Female		-0.001		0.000
× Area centered		(0.002)		(0.003)
Female; Child < 18; Interactions	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.966	0.977	0.960	0.969
KPW F-Stat			100.390	17.111
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. The parent group is restricted to those with a child below 18 years old. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x parent x year group in 1st stage. The dependent variable is the urban area x gender x parent x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of childless men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

Table A5: Second-stage FE regression results, by gender and parental status (under 10 y.o.)

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.096***	0.049***	0.089***	0.014**
	(0.015)	(0.005)	(0.016)	(0.006)
Female × Density centered	0.050***	0.021***	0.060***	0.029***
	(0.011)	(0.006)	(0.012)	(0.007)
Child < 10 × Density centered	0.006***	0.004***	0.006***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Child < 10 × Female × Density centered	-0.006***	-0.009***	-0.006***	-0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
Area centered		0.039***		0.069***
		(0.004)		(0.005)
Female × Area centered		0.024***		0.027***
		(0.005)		(0.008)
Child < 10 × Area centered		0.001*		-0.002**
		(0.000)		(0.001)
Child < 10 × Female × Area centered		0.002*		0.003
		(0.001)		(0.002)
Female; Child < 10; Interactions	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.967	0.978	0.962	0.970
KPW F-Stat			145.118	14.087
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. The parent group is restricted to those with a child below 10 years old. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x parent x year group in 1st stage. The dependent variable is the urban area x gender x parent x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of childless men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

Table A6: Second-stage FE regression results, by gender and parental status (child under 6)

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.096***	0.048***	0.090***	0.015***
	(0.014)	(0.005)	(0.016)	(0.005)
Female × Density centered	0.051***	0.024***	0.058***	0.028***
	(0.008)	(0.004)	(0.009)	(0.005)
Child < 6 × Density centered	0.004***	0.002**	0.004***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Child < 6 × Female × Density centered	-0.008***	-0.013***	-0.005*	-0.009***
	(0.003)	(0.003)	(0.003)	(0.003)
Area centered		0.040***		0.069***
		(0.004)		(0.004)
Female × Area centered		0.022***		0.026***
		(0.004)		(0.005)
Child < 6 × Area centered		0.001**		-0.002***
		(0.000)		(0.000)
Child < 6 × Female × Area centered		0.004***		0.003
		(0.002)		(0.002)
Female; Child < 6; Interactions	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.953	0.969	0.939	0.953
KPW F-Stat			144.984	11.627
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. The parent group is restricted to those with a child below 6 years old. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x parent x year group in 1st stage. The dependent variable is the urban area x gender x parent x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of childless men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.

Table A7: Second-stage FE regression results, by gender and parental status (child under 3)

	OLS		IV	
	(1)	(2)	(3)	(4)
Density centered	0.095***	0.046***	0.090***	0.015***
	(0.014)	(0.005)	(0.015)	(0.005)
Female × Density centered	0.052***	0.028***	0.056***	0.027***
	(0.007)	(0.003)	(0.007)	(0.004)
Child $<$ 3 × Density centered	0.004***	0.001	0.004***	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)
Child $<$ 3 × Female × Density centered	-0.012	-0.026***	-0.003	-0.011
	(0.012)	(0.009)	(0.013)	(0.008)
Area centered		0.040***		0.069***
		(0.004)		(0.003)
Female × Area centered		0.019***		0.025***
		(0.002)		(0.003)
Child $<$ 3 × Area centered		0.001***		-0.001*
		(0.001)		(0.001)
Child $<$ 3 × Female × Area centered		0.011*		0.006
		(0.007)		(0.010)
Female; Child $<$ 3; Interactions	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Historical IV	No	No	Yes	Yes
Soil IV	No	No	Yes	Yes
R^2	0.925	0.950	0.873	0.899
KPW F-Stat			145.167	10.608
N	5472	5472	5424	5424

Note: This table is computed from Fideli data. The sample is made of individuals aged 25-60 living in urban areas in mainland France. The parent group is restricted to those with a child below 3 years old. Robust clustered (urban area × year) standard errors in parentheses. Regressions weighted by the size of each city x gender x parent x year group in 1st stage. The dependent variable is the urban area x gender x parent x year fixed effect obtained from equation 1, in which the outcome variable was the log of work income. Density and area are in logarithm, centered around the mean of childless men. Historical instruments are historical population density in 1861, 1931 and 1954 . Geological instruments are proportions of the city area by levels of depth to rock, soil erodability, hydrogeological class, subsoil mineralogy and topsoil organic carbon content.