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The Effect of Heat on Fertility Rates in France

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Abstract

I estimate the effects of heat on fertility rates in France from 1975-2020. I find that days with a mean daily temperature above 25 C have an estimated effect of 0.260 and 0.256 percent on Total Fertility Rates nine and ten months later, respectively. I find that this relationship has become smaller over the window of analysis, and is heterogeneous at the sub-national level, with fertility rates colder regions being affected at lower temperatures than in hot regions. I discuss the potential roles of policy and air conditioning in mediating the relationship between heat and fertility. I also find that this relationship is relevant across alternate methodologies. These findings suggest that the heat/fertility relationship is an important factor in broader debates on the population aging of Europe and the diversity of health risks posed by climate change.

Chapter 1

Introduction

Industrialization has led to an unprecedented release of carbon dioxide and other greenhouse gasses into the earth's atmosphere. This has caused, within a span of decades, changes to our climate the magnitude of which have only previously been known on our planet over the span of geological eras. The term "climate change" refers to complex shifts in our oceans and atmosphere that no person or computer model can fully predict. In the face of this complexity, climate change is often distilled into tangible events that these planetary changes are contributing to: floods, hurricanes, drought, famine, pollution, heat waves, and more.

Of all these hazards, none is more deadly or ubiquitous than heat waves. The Intergovernmental Panel on Climate Change (IPCC) states that globally, heat waves are becoming more frequent and severe because of climate change (Intergovernmental Panel On Climate Change 2023). Consequently, heat is forecasted to cause the largest share of the climate change death toll in coming decades (World Health Organization 2014).

Despite heat waves representing one of the most consequential hazards of climate change for human health, they remain an ill-defined and elusive subject of study for both natural and social sciences. To begin, it is difficult to define a heat wave. The World Meteorological Association, the IPCC, and national governments each offer their own version of what constitutes a heat wave. Policymakers and different academic disciplines may also disagree over what constitutes a heat wave. Adding complexity still, all these metrics may not fully capture the lived experience of populations during heat waves (Boni et al. 2023). Chapter 2.3.2 will explore further the challenges in governing heat waves at the national and international context.

All these definitions of a heat wave means it is difficult to systematically catalog their effects. The full extent of health and consequent demographic effects of heat waves are not completely known. While the health risks of heat waves remain underestimated (World Health Organization 2024), past events such as the 2003 heat wave in Europe have contributed to an increased policy awareness of the risks heat waves pose to vulnerable populations. The connection between heat and mortality is most obvious. While the aforementioned ambiguities in defining a heat wave have rendered research on heat and mortality somewhat fragmented, there is still a wealth of evidence supporting that the ill, elderly and poor are at most risk to die during heat waves (Klinenberg 2002; Keller 2015).

The effect of heat on fertility, in comparison, is much less explored within demographic inquiry. Of the three core dynamics of demographic inquiry, fertility, mortality and migration, the effects of climate change on mortality and migration are much more researched than their effects on fertility within the discipline of demography. For example, a review of environmental demography by Hunter and Simon (2021) devotes much more space to research concerning mortality and migration than fertility. The review describes how floods and hurricanes may affect fertility dynamics, and does not mention heat waves as a hazard relevant to fertility outcomes, despite being a more ubiquitous climate change hazard. Yet, there exists a small body but growing body of research published elsewhere that has begun to coalesce around the negative effect of heat on fertility (A. Barreca, Deschenes, and Guldi 2018; Cho 2020;

T. Hajdu and G. Hajdu 2022; Marteleto, Maia, and Rodrigues 2023; Conte Keivabu, Cozzani, and Wilde 2023).

There are several possible reasons for this lack of popular and academic attention towards the possible effect of heat on fertility. First, there is the visibility of the issue. When a heat wave turns into a mass mortality event, news media may share images of overflowing hospitals and morgues and warn the public to check in on elderly relatives and neighbors (Klinenberg 2002; Keller 2015). A negative effect on fertility, however, emerges months after the heat has passed. Specifically, the body of work cited in the previous paragraph has noted that effects mainly emerge nine and ten months after a heat wave due to disruptions in spermatogenesis causing a decline in conceptions shortly after a heat wave. The effects of heat on fertility are evidenced by a statistical irregularity, not as dire footage on the evening news, and noticed only by a few social scientists. Another reason for this lack of visibility is that the effect is rooted in adverse health effects that may apply to otherwise young and healthy people. This is a group normally not imagined to be at risk during a heat wave. Therefore, this topic demands that we consider every portion of the population as somehow vulnerable to heat, not just the old or infirm.

In order to illustrate that it is possible to conceive of the effect of heat on fertility as a phenomenon visible at the same scale as the readily recognized effect of heat on mortality, I take fertility and mortality rates around the severe heat wave of 2003 as demonstration of their relative fluctuations due to a period of extreme heat.

Figure 1.1 displays month specific fertility and mortality rates during the 2003 heat wave compared to years before and after where no such shock occurred. This approach is common in epidemiology, wherein the death toll from an event is calculated by finding the expected mortality figure based on the same month in surrounding years, and any positive deviation is labeled as “excess deaths.” The effects on mortality are clear: August 2003 stands as an outlier compared to the same month in the years before or after.

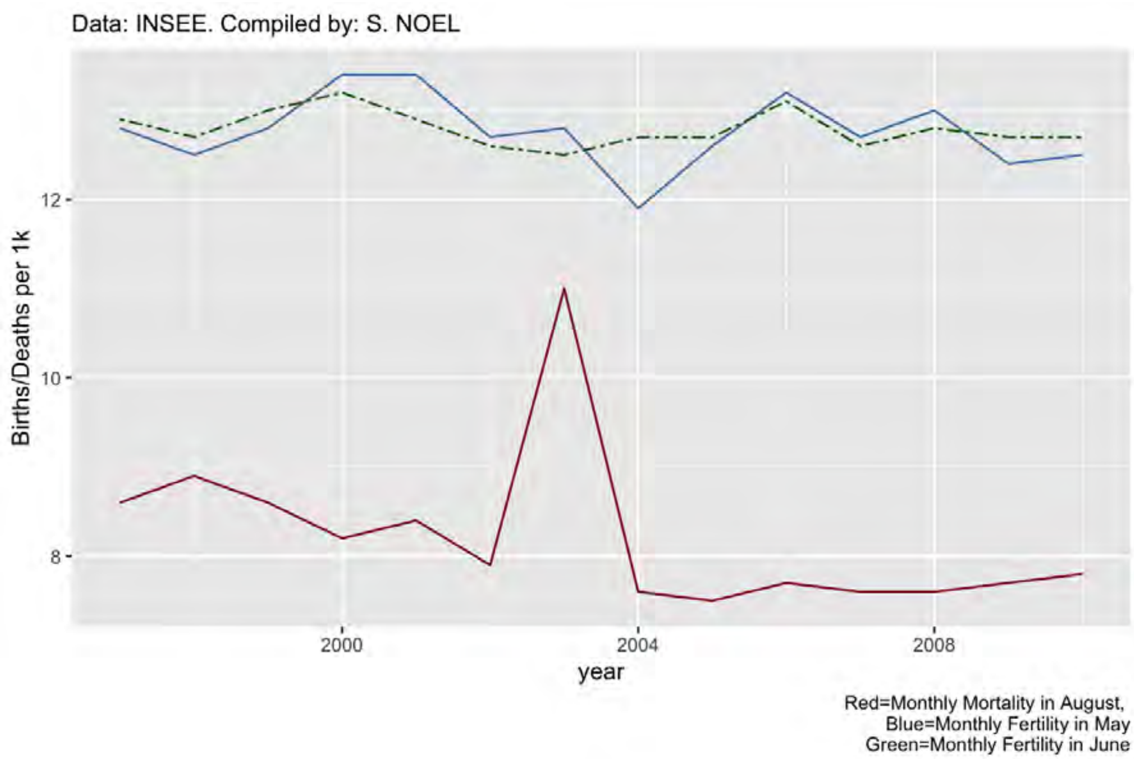

Figure 1.1: Fertility and Mortality in France and the 2003 Heat Wave

The blue and green lines represent fertility rates in the months of May and June for the years around 2003. Due to the specific timing of the August 2003 heat wave, we expect to observe the effect on fertility from the heat wave of August 2003 in May 2004, and to a much lesser extent in June 2004. For the years before and after the heat wave, Figure 1.1 shows that the fertility rates in May and June are normally very similar. This is expected, since fertility rates in France tend to gently vary by season, not from month to month. May 2004, however, stands as an anomaly. The fertility rate of May 2004 is noticeably lower than its June complement in that same year. The 2003 heat wave stands as the most plausible explanation for this anomaly (Régnier-Loilier 2010).

Figure 1.1 displays fertility rates and mortality rates on the same scale: normalized to 1,000 inhabitants. The magnitude of the mortality shock is clearly larger. In this particular heat event, the effect of heat on mortality was around three times as large as its effect on fertility. Figure 1.1 serves not to advance the core causal claim of this mémoire, but to illustrate that even if the immediate effects on fertility are smaller, in absolute terms, than mortality, that this effect on fertility is even visible on the same scale is significant in light of how little is understood about the heat/fertility effect compared to the heat/mortality effect.

So far, I have evoked the accelerating pace of climate change as a reason for which the effect of heat on fertility rates is a research subject worth further development. Another dynamic which heightens the relevance of this topic is the acceleration in fertility decline in France and across western countries- wherein any burgeoning negative effect of heat on fertility might serve exacerbate current fertility decline.

The average fertility rate of OECD member countries from the mid 1990's until 2014 was stable at just under replacement rate (around 1.8 children per woman). Since 2015 the OECD average fertility rate has fallen to 1.6 in 2021 (The World Bank 2024). Even in countries with historically robust fertility rates and strong safety nets such as the Nordic countries and France have been party to this decline (The World Bank 2024). There are multiple explanations for this decline in fertility.

For one, McDonald (2000) explains that increasing gender equity in individual institutions such as labor force participation and formal education play a significant role in lowering fertility rates, as women may increasingly engage in life projects other than family formation. At the same time, that persistent inequalities can be still found within family roles make women more reticent to give up these projects outside the home and become constrained by their role in the family. Lesthaeghe (2010) widens this idea to explain what he coins the "Second Demographic Transition." Lesthaeghe posits that if fertility rates declining in western countries from above replacement rate to around replacement rate constitutes the *first* demographic transition, then fertility trends in western countries falling below replacement rate must be considered a *second* demographic transition, replete with its own unique causes.

Fundamentally, Lesthaeghe attributes this second stage of fertility decline to a shift in post-materialism in western societies. When a society achieves material sufficiency preferences shift to higher order needs, as first defined by Maslow (1954) such as recognition or self-expression, rather than the values of cohesion and unity borne by a period of material scarcity. This rise in status of the individual relative to the community subsequently leaves room for young adults to weigh if having children is a life project aligned with their individual preferences, instead of accepting the communal expectation. Lesthaeghe (2010) also points out that the erosion of the insititution of marriage, postponement of parenthood, and the advent of effective birth control further contributes to the suppressed fertility rates seen in the second demographic transition. Outside the discipline of demography, economists such as Gary Becker (1991) have theorized that with the increased possibilities enjoyed by women as described by Lesthaeghe, the *opportunity cost* of having children, meaning the loss of wages resulting in time away from the labor market, has increased. Therefore, childrearing has become less attractive not just from a the Maslowian perspective of self-actualization, but from a rational choice economic viewpoint as well.

Relatedly, researchers have found that current economic insecurity among young adults within the housing and labor market leaves individuals wary of raising a family (Philipov, Liefbroer, and Klobas 2015). For many young people, it is difficult enough of a life project to establish some stability for themselves, let alone the costs of raising a family. This uncertainty across several avenues has meant that more and more individuals postponing childbirth, even among the highly educated. Other factors are more cultural than economic. In recent years, a growing uncertainty about the climate crisis has led to more and more individuals deciding to not have children (Dillarstone, Brown, and Flores 2023). The combination of all these factors have contributed to precipitous drops in fertility rates across many EU countries from the 2010's to the present. While climate change stands as a relatively minor factor in global fertility decline today, the accelerating pace of climate change means its relative importance among other factors is likely to increase in coming decades.

There are many political and social effects of an aging population. Fundamentally, the economic engine of any country is a robust supply of labor. Some of the value of that labor, through taxes, is converted into welfare for the elderly or those otherwise unable to work. When less and less workers must finance more and more elderly people, the economic burden on each individual worker increases. As a consequence, population aging may contribute to declines in economic demand and in the standard of living of a population. In short, population aging threatens the economic viability of countries across Europe.

Furthermore, fertility rates have a long-run, cumulative quality, often referred to as *demographic momentum*. This means that any changes to fertility rates tend to reinforce themselves. For example, a decreased fertility rate means, in several decades, there will be less women of reproductive age. Even if policies encourage this smaller pool of women to have more children per capita than in years past, that this pool of women is smaller to begin with is difficult to compensate for. Since previous research the effect of heat on fertility rates is both observable and permanent (i.e. there is no short term, positive rebound), it is a relevant factor in shaping the long-run age structure of a given population.

Population aging may also be considered a social problem in addition to an economic one. A growing body of research shows that while fertility rates have declined, fertility *intentions* have remained comparatively elevated in the European context (Testa 2014). Evidence on the French context also shows a gap between intended and actual fertility (Toulemon and Testa 2005). Therefore, the current fertility decline cannot be understood as a problem strictly of changing preferences, but also of increasing constraints. With this understanding, fertility decline signifies not just a problem at a macroeconomic level, but at a micro social level, via the possible loss of social well being in not achieving anticipated life projects.

For these reasons, in the past decade EU states have firmly classified fertility decline as a social problem worthy of policy solutions, particularly through the levers of the welfare state via widespread access to early childcare and other supportive welfare policies that seek to lower the economic and social burden of having children by de-familising the responsibilities of child rearing (Neyer et al. 2013). Yet, recent years have seen declines in fertility even in these most ambitious welfare states, meaning that state welfare policies hold no perfect answer *all* the reasons for this broader decline described previously. The acceleration of fertility decline in the face of attempted policy solutions has only strengthened the position of EU states in classifying declining fertility as a policy problem. In France, in January 2024 President Emmanuel Macron, has called for nothing less than war footing against the low fertility threat, advocating for a suite of policies under the banner of ”demographic rearmament” (Cordier 2024).

This definition of declining fertility rate as a social problem to be solved through top-down policies is not without tension. Some scholars and activists have posited that declining fertility rates may be a *good* development. There are several intellectual avenues that have advanced this argument.

First, we may consider the rise of a philosophically backed anti-natalism e.g. (Benatar 2008) stating that the harms and hassles of life outweigh the positive aspects, and therefore it is unjust to have children and doom them to sentience. This argument has been fought to something of a draw with the inverse claims of philosophical optimism e.g. (DeGrazia 2010) arguing that by several survey measures, people across country contexts regard life as worth living. In more recent years, dire headlines of climate disaster have brought this debate from philosophical to popular discourse. This ecologically minded antinatalism emerges through several claims, such as how worsening climate disasters mean a worse quality of life for children born today than in the past, or that individuals in high income countries have high carbon footprints, and so a decline in fertility in these high income countries is a net positive for the future of carbon emissions.

I consider here that this stance, debatable today, is not stable enough to consider the decline in fertility described in this mémoire as an unqualified good. First, in considering the uncertainties involved in forecasting the pace of future climate change, it is impossible to conclude to what extent future decades will be "worth living" (if it is even possible to collectively define such a term). Second, individuals residing in high income countries will not be able to compensate, through their childbearing decisions, with the wider failures in the governance in climate change in recent years that will define the century to come. Successions of COP conferences in this decade have failed to produce meaningful aid low-income countries in coping with climate change in a emission friendly manner. Therefore, as emerging economies grow in population, they also grow in their economic power to consume both lifesaving and highly emissions intensive consumer goods such as air conditioning (Sovacool et al. 2021). These complications at a global governance level means that fertility choices of individuals residing in high-income countries can be considered, at best, only a partial remedy to a rapidly worsening problem. We may conclude however, that whether declining fertility rates linked with climate change are a "good" or a "bad", they are certainly a matter of public interest: both for the negative macroeconomic effects and the more fraught public debate concerning a new ethics in the face of unprecedented environmental change.

I have thus far described how understanding two dynamics, climate change and fertility decline, is becoming highly important to both academic research and public policy across sectors. That fertility decline is accelerating concurrently with the acceleration of climate change means that research not just on the two dynamics as independent entities are needed. The burgeoning literature on the effect of heat on fertility suggests that the *inter*dependence of these two dynamics is both relevant and, at this point, under researched relative to its importance across a diverse array of policy and academic debates.

My mémoire contributes to this research in two ways. The first is it addresses an empirical gap. There is only one study that measures the effect of heat on fertility rates in France. Régnier-Loilier (2010) uses an epidemiological approach, comparing fertility in years surrounding the heat shock to the fertility rate following heat waves. More recent work on this subject studying the U.S. (A. Barreca, Deschenes, and Guldi 2018), Spain (Conte Keivabu, Cozzani, and Wilde 2023) South Korea (Cho 2020), Hungary (T. Hajdu and G. Hajdu 2022) and Brazil (Marteleto, Maia, and Rodrigues 2023) and the European continent (T. Hajdu 2024) has converged upon a different methodological approach: the use of fixed-effects modelling to more comprehensively isolate the effects of heat on fertility from other spatial and temporal confounders. This mémoire adopts such a fixed-effects approach, and thus builds upon the findings of Régnier-Loilier. I will compare the the effect of extreme heat on fertility rates in France during the period of 1975-2020 with the results that exist for other countries.

The second contribution of this mémoire is a methodological one. As is the case in broader academic and policy contexts, this research stream has no uniform definition of a heat wave. My analysis will test competing methodologies within the same country context in order to contribute to this methodological debate.

To make these contributions, this mémoire will proceed in 5 Chapters.

Chapter 1 contains the literature review, which embarks upon several objectives. First, Section 2.1 seeks to place this mémoire within wider trends in sociology. I describe how both long term and recent trends in sociology have contributed to a formation of an environmental sociology that at once benefits from an interdisciplinary spirit in data use, while maintaining the value of sociological hypotheses concerning the avenues through which heat comes to affect human health. I describe how this mémoire benefits from a diversification in sociological inquiry to encompass meteorological variables, and technical advances needed to process such variables for use in social science research. I also highlight an intersection between previous sociological work on heat and mortality, and recent literature on heat and fertility regarding the importance of housing quality, particularly air conditioning, in moderating the effect of heat on health over space and time. I further develop this theoretical intersection within the empirical analysis of this mémoire.

Sections 2.2 and 2.3 dissect the two central variables of this mémoire: fertility rates in France and hot weather in France. Section 2.2 describes the evolution of regionality and seasonality of births in France, dynamics that must be understood and accounted for when seeking to estimate uniquely the effects of an exogenous, but still seasonal, weather shock within a several decades long period of analysis. Section 2.3 elaborates on the specific mechanisms of hot weather in France, and how this is changing over time. I note that hot weather cannot be simplified into a random probability event observed only by a spontaneous spike the numbers on a thermometer. Instead, it is a complex event implicating changes in humidity, wind and air pollution known colloquially as a "heat dome" that has a range of effects on human health. I therefore seek to reflect this complexity in subsequent sections of my empirical analysis. Such events are becoming more common at a pace that has surprised both policy makers and planetary scientists, which heightens the future implications of this work.

Next, I review the contributions of medical and social science literature (Section 2.4) in measuring and explaining the effects of heat on fertility in different country contexts. In Section 2.5 I discuss two potential moderators of this relationship: public policies that address heat wave risks, and air conditioning prevalence, which have both have 1) a theoretical foundation in the sociological literature on heat and mortality, and 2) emerging empirical evidence within previous analyses on the relationship between heat and fertility.

In the final section of Chapter 2, I restate the hypotheses that I have formulated throughout the chapter that reflect trends in proximate empirical literature on heat and fertility, theoretical contributions of sociologists on the distribution of heat risks, and applied to case specifies of French fertility dynamics and climate.

In Chapter 3, I describe the data and methods at the core of this mémoire. I discuss the challenges in obtaining comprehensive, sub-national fertility data (Section 3.1), and how only very recently has it become reasonably accessible to convert large meteorological datasets for use social science research (Section 3.2). To conclude this chapter, I discuss the estimation technique used to bring together these two datasets and account for confounding meteorological and demographic dynamics described in earlier sections.

Chapter 4 contains the results from this core estimation technique (Section 4.2). I confirm that the effect of heat on fertility seen in other country contexts is also visible in France. I also estimate that the heat/fertility relationship decreases over time (Section 4.3), and is heterogeneous the sub-national level (Section 4.4). I test the core results under different definitions of a ”hot day” and different functional forms (Section 4.5 through 4.7). I find that the overall link of heat and fertility holds under different operationalizations.

Chapter 5 contains a conclusion which summarizes the main findings and the limitations of this study and how future research could build upon the findings presented in this work, and a discussion of the implications of these findings.

Chapter 2

Literature Review

2.1 Sociology and the Environment

2.1.1 The Evolution of Environmental Sociology

Several handbooks of environmental sociology cite Catton and Dunlap's 1978 article, "Environmental Sociology: A New Paradigm" as the foundational text of the subfield (Catton and Dunlap 1978). At the time of publishing, American intellectual thought and society at large was growing increasingly anxious about environmental issues, owing to journalistic works such as Rachel Carson's "Silent Spring" and contemporary events such as the oil shocks throughout the 1970s. Catton and Dunlap joined the voices of concern, stating that seemingly rival streams of sociology, from Marxism to Functionalism, all agree on a "human exceptionalism paradigm" that shapes sociological inquiry. Catton and Dunlap defined the human exemptionalism paradigm as an assumption that human activity unfolds upon a non-reactive canvas of the environment, an assumption they believed recent events had exposed as naive. Catton and Dunlap proposed an alternative paradigm, the "New Ecological

Paradigm", which understands human society as just one part of an interdependent "biotic community" subject to "potent physical and biological limits" due to finite planetary resources.

In their vigorous effort to carve out a new direction for sociology, early environmental sociologists saw little use for classical theorists. In subsequent decades, this first generation of environmental sociologists returned to classical theory in search of retrospective genesis of environmental sociology. These theorists argue convincingly that sociologists had been writing about the interaction of human societies and their environment since the very start of the discipline. The nascent discipline of sociology was much more intellectually diverse than commonly understood, and that a substantial amount of articles in early sociological journals included environmental perspectives (Holleman 2020). Some sociologists have also uplifted some less acclaimed, yet still foundational sociologists such as Frédéric le Play, who considered the interdependence of humans and their environment. Furthermore, rereadings of the founding fathers of sociology, Weber, Durkheim and especially Marx, found that they occasionally considered the role of the environment in shaping society and vice versa in less cited works (Holleman 2020).

While the rediscovery of environmental themes within discussions of classical sociology remains of epistemological interest to environmental sociology, it cannot be said that environmental sociology has proceeded on the basis provided by these classical thinkers. This revisitation of classical sociology showed that the founding scholars of sociology worked hard to distinguish sociology from the dominant natural sciences of the time (Candau and Deldreve 2015). Marx, Weber, and Durkheim each sought to differentiate their new field of sociology from the dominant scientific fields of the nineteenth century. Durkheim's notion of collective "social facts" separated sociology from the more individualistic field of psychology (Dunlap 2002, pp. 38). Marx's historical materialism sought to refute Malthusianism (Dunlap 2002, pp. 39). Weber's understanding of human societies determined by "human motivations and history" stood as a rejection of the evolutionary reasoning dominant at the time (Dunlap

2002, pp. 41).

The foundational thinkers of sociology kept environmental perspectives at the periphery of their works not because they believed it to be wholly unimportant to social life, but because the project of founding a new discipline made it inconvenient to acknowledge the interlinkages between these different sciences (Candau and Deldreve 2015; Holleman 2020). This kind of thinking was not rare at the second half of the nineteenth century. This period saw disciplinary boundary building at its peak (Monk, Easton, and Schelling 1992). Consequently, environmental sociology has not refashioned the fragmented environmental theories of classical sociologists into a suitable theoretical engine for environmental sociology. Instead, the field has simply taken the work of Catton and Dunlap (1978) as its theoretical foundation, with all subsequent handbooks of the field citing their delineation of the field as the subdisciplinary touchstone.

In the decades following Catton and Dunlap's article, American environmental sociology often manifested as a "sociology of environmental issues" content to operate under the "normal science" of sociology by focusing on classic sociological subjects such as public action and collective action as they appear in environmental issues (Dunlap and Michelson 2002). In the French context, environmental sociology of the 1970's and 1980's was defined by two pre-existing traditions. The first tradition was rural sociology and its focus on the interaction of modernization and agriculture. The second tradition was the theory of distinction and its application to how social classes interact with nature (Candau and Deldreve 2015). In sum, the environmental sociology from 1978 to the early 2000's still relied on the typical frameworks of sociology and applied them to subjects with some sort of environmental connection.

From the 2000's to the 2010's, environmental sociology developed beyond these frameworks and today more closely resembles the original ambitions of Catton and Dunlap (1978) for an entirely new sociology that places social and environmental variables on equal footing in order to describe the "intricate linkages of cause and effect" between the two. This evolution was made possible by two developments. The first development was a theoretical one. In both the French and American contexts, sociology became more open to interdisciplinary research. Sociology consisting strictly of a social understanding of human society has gradually fallen out of fashion. Relatedly, popular concern regarding highly complex issues such as artificial intelligence and climate change has spurred cross-disciplinary collaboration across the natural and social sciences. Therefore, current generations of environmental sociologists that incorporate biophysical considerations in their research are not dismissed as "doing biology" as they may have been in previous decades (Candau and Deldreve 2015).

Beyond the boundaries of sociology, the threat of climate change has fueled a rise in a variety of interdisciplinary research agendas, for example in the new field of planetary health, that exists at the intersection of public health and earth science (Myers and Frumkin 2020). Still, the research that has emerged from these interdisciplinary streams is not distant from what environmental sociologists have aspired for their discipline to achieve: the inclusion of environmental variables within inquiry on social life (Dunlap and Brulle 2015, Chapter 12). This mémoire combines meteorological and demographic data to be analyzed through a sociological lens. As such, it is a work of environmental sociology- interdisciplinary with the aim of enriching sociological inquiry.

The second factor that has contributed to the development of environmental sociology is a methodological one. One of the most substantial differences between the Handbook of Environmental Sociology published in 2002 (Dunlap and Michelson 2002) and more recent handbooks published in 2015 (Dunlap and Brulle 2015) and 2020 (Legun et al. 2020) is that the most recent handbooks contain extensive discussions of meteorological data and related methodologies. This is because since the early 2000's there has been a marked increase in both the capabilities and availability of meteorological data, and geographic information systems (GIS) softwares needed to process such data. These developments have let researchers within environmental sociology to design research projects that more closely resembles Catton and Dunlap's highest aspirations of the field by including detailed meteorological and social data within the same analysis. Along these lines, this mémoire takes advantage of highly detailed weather data that has only been publicly available since the mid 2010's (Cornes et al. 2018). This mémoire also takes advantage of R packages made available only in the last couple years that support the computations that renders these datasets usable for social science research (Schmucki 2023). In sum, the methodology and topic of this mémoire fit into to broader changes in sociology as a discipline.

2.1.2 Heat Waves in Environmental Sociology

Next, I will discuss more specifically the theoretical frameworks of today's environmental sociology, and how they contribute to the theoretical framing of heat waves and health risks within this mémoire. The current form of environmental sociology has emerged in tandem with the sociology of risk and the sociology of inequalities. The founding social theorists of the sociology of risk, Ulrich Beck (1992) and Anthony Giddens (1997), were broadly interested in the risks that modernity had made both unavoidable and more potent. Such risks included pandemics, nuclear weapons, and especially environmental issues. Beck and Giddens argued that these new risks were often unequally distributed upon members of society, and that institutions play a key role in the management of such risks (Caplan 2000). Building on these works, Benjamin Wisner (2004) and Kathleen Tierney (1994) proposed an understanding of natural disasters viewed not by the physical event, but by the social processes that cultivate vulnerabilities among some populations but not others. Subsequent research on climate inequalities has affirmed that on a country, regional, and individual level, those who suffer most from the effects of climate change are populations who have already been disadvantaged through a variety of other social processes. The persistence of this finding across space and time has led to the concepts of risk and vulnerability to be ubiquitous in environmental sociology, and indeed more broadly in social science research on climate change.

Eric Klinenberg's seminal work, "Heat Wave: A Social Autopsy of Disaster" (Klinenberg 2002) employed these themes of risk and vulnerability to pioneer the study of heat waves as a sociological object. Klinenberg employs both qualitative and quantitative methods to understand spatial, racial, and socioeconomic discrepancies in mortality during the 1995 heat wave in Chicago. Klinenberg's main theoretical contribution is that mortality from heat waves is not an inevitable act of fate, but evidence of various social causes: isolation, poverty, energy policy, media coverage, housing quality, and more.

Building on Klinenberg, environmental historian Richard Keller's work "Fatal Isolation" (Keller 2015) completes a similar social autopsy regarding the 2003 heat wave in Paris. Keller adopts a similar mixed methods approach to Klinenberg. Keller analyzes mortality statistics and interviews people who knew individuals that died during the heatwave. Keller's findings on the vulnerability of social isolation and poverty align with Klinenberg's work. In particular interest to this thesis, Keller illustrates the specificity of Parisian building construction in exacerbating the negative health effects of hot weather.

Together, Klinenberg and Keller's work offer a direction for the sociological study of heat waves. Broadly, both Keller and Klinenberg affirm the the importance of social causes in constructing vulnerabilities to heat waves. Keller and Klinenberg both begin from what they see as a common misconception of heat mortality: that it is simply an unfortunate physiological process involving the failure of already frail bodies to compensate for increased thermal stress. Both authors argue convincingly that it is more complicated. They emphasize that social and physical infrastructure are central to understanding heat wave vulnerabilities, including the effects of individual mobility, social support, housing quality, age, socioeconomic status, and public policy. I do not aim to examine each of these dynamics here. Some are specific to the problem of mortality (like age) while I am limited in data availability regarding others, like socioeconomic status. I therefore concentrate on the possible mechanism of housing quality, in particular air conditioning, which features both data availability at the regional level and some prior evidence in promoting resilience within the heat/fertility literature.

Namely, the work of Barreca et al. (2018) posits that spatial and temporal decreases in the effect of heat on fertility rates may be explained through the adoption of air conditioning. Given this overlap between the sociological and heat/fertility literature, I also investigate the possible role of air conditioning in moderating the effect of heat on fertility in France. An important caveat here is that I cannot treat sub-regional heterogeneity in housing quality, and their likely correlation with socioeconomic status. Keller and Klinenberg also highlight the relevance of public policy in mediating heat risks within a population. Given that the window of analysis of this mémoire (1975-2020) encompasses several decades and consequent heat wave policy developments in France, I consider possible temporal effects of such policies.

The link between this work and the work of Klinenberg and Keller is more conceptual than methodological. This mémoire does not take a mixed methods approach as does Klinenberg and Keller. This is because much less is known about the effect of heat on fertility than on mortality. For Keller and Klinenberg, a qualitative approach was necessary to add a discussion of mechanisms behind the relationship between heat and mortality: the relationship was already apparent. The literature on fertility, by comparison, is still establishing to what extent the effect exists in different contexts. Simply put, since the literature of heat and fertility is not as advanced as as the literature of heat on mortality, more work remains to be done on *existence* of a link before it might be possible to engage in explaining the link in detail via other methods. Additionally, fertility data is commonly available only in spatial aggregations for privacy reasons. Mortality data may be much more granular, especially when researchers have access to individual death certificates. Therefore, because of the frontier of the subject and the data limitations of fertility rates, this mémoire cannot mimic the ethnographic approach accomplished by Keller and

Klinenberg, though their theoretical contributions are still useful.

Few studies in the heat/fertility literature are able to comprehensively study the moderating role of individual socioeconomic status. However, given that previous sociological work on heat waves finds such distinctions highly relevant, it is reasonable to hypothesize that the relationship between heat and fertility may vary by socioeconomic status as well. Conte Keivabu and Cozzani (2023) report ambiguous results regarding the role of SES status on the relationship between heat and fertility. In the case of Spain, they find no difference in effect with regards to maternal SES or maternal age, though they observe a more substantial catch up effect among high SES mothers. Barreca et al. (2018), using state level data in the US find that AC adoption is associated with a statistically significant protective effect on birth rates following a heat shock, and that the role of education and labor in mediating the heat/fertility relationship yields ambiguous results. Cho (2023) also finds little evidence in South Korea regarding the influence of maternal characteristics in the relationship between heat and fertility.

Even though the literature on fertility and heat has not reached a conclusion on the role of social factors, similar research considering the effects of heat on adverse birth outcomes has made more progress incorporating socioeconomic factors. Negative birth outcomes and negative shocks in fertility due to heat are both rooted in reproductive health. Therefore, it is worthwhile to look at this adjacent literature for hypotheses on the role of social factors mediating the relationship between heat and fertility rates.

Researchers in studying heat and birth outcomes commonly rely on individual level birth certificate data. Such data includes birth weight, birth date, and information on the parental occupation. Consequently, this research is able to link outcomes such as birth weight, with the socioeconomic status of the parents. While Conte Keivabu and Cozzani (2022) find that in the Spanish case, lower SES individuals are more vulnerable to adverse birth outcomes, other studies on South Korea (Cho 2020) and

Hungary (T. Hajdu and G. Hajdu 2022) found no difference in adverse birth outcomes between different socioeconomic groups. One study in California even found larger risk borne by high SES individuals, possibly due to highly educated women postponing pregnancy and therefore having higher risk pregnancies (Basu et al. 2018). This suggests a high level of country context dependence in how socioeconomic status may influence the relationship between heat and birth outcomes, depending on housing, age structure, and climate, that may also be the case concerning the effects of SES on mediating the relationship between heat and fertility.

Here, the context of France emerges as a valuable case study for the heat/fertility literature in considering how the heat/fertility relationship may be mediated within a population. The climate of France varies to include many of the climate types seen in the western portion of the European continent. At the same time, AC adoption rates are similarly low to Spain, yet there are some sub-regional differences in this regard that support further analysis. Therefore, studying France not only contributes to an empirical gap in this literature, but permits this literature to analyze a possible relationship between AC and a variety of local climates within a unified national context.

To summarize, in reviewing current sociological literature on heat wave risks, I incorporate perspectives on housing quality, specifically AC adoption, as well as relevant public policies in shaping the relationship between heat and fertility. Before developing further these potential moderators, the next sections will review key dynamics within the central variables of this mémoire: fertility rates and hot weather in France.

2.2 Existing Demographic Trends in France

2.2.1 Seasonality of Births in France

This section explains the pre-existing seasonal and regional trends in births that must be accounted for in the later estimation technique that aims to study effects of climate shocks on fertility, outstanding of these underlying dynamics. Globally, fertility rates fluctuate seasonally. Across cultural and environmental contexts, conceptions tend to increase in cooler, drier seasons, and decrease in hot seasons (Wesselink et al. 2020). Birth patterns in France also follow this trend, though the dynamic has evolved over time. In the 17th and 18th centuries, births peaked in February and March (Dupâquier 1976). This is generally attributed to reasons “outside the individual” (Régnier-Loilier and Rohrbasser 2011). One such reason was the harvest season, wherein Hourdaille (Mar. 1985) notes the physical toll of the autumnal harvest may have led to less conceptions during this time of year, particularly in rural communities. Another reason was the religiosity of French society during this period, and consequent observation of the Christian calendar. The Christian calendar forbids conjugal relations during Advent and Lent, and calls for fasting during Lent, both of which may have negatively affected conceptions (Régnier-Loilier and Rohrbasser 2011). This peak of fertility in February and March diminished over the 17th and 18th centuries, as nutritional standards improved and religiosity decreased (Régnier-Loilier 2010).

Beginning in the middle of the 20th century, this peak began to change its place within the year. The introduction of paid vacation in 1936 led to more conceptions in the summer months, particularly August (Dupâquier 1976). Consequently, by the 1950’s, the annual birth peak had moved from early spring to late spring (Régnier-Loilier 2010). The springtime peak of births persisted through the 1980’s, as the legalization of birth control in 1967 allowed couples more control over their birth planning. The seasonality of marriages during the 1970’s and 1980’s also contributed

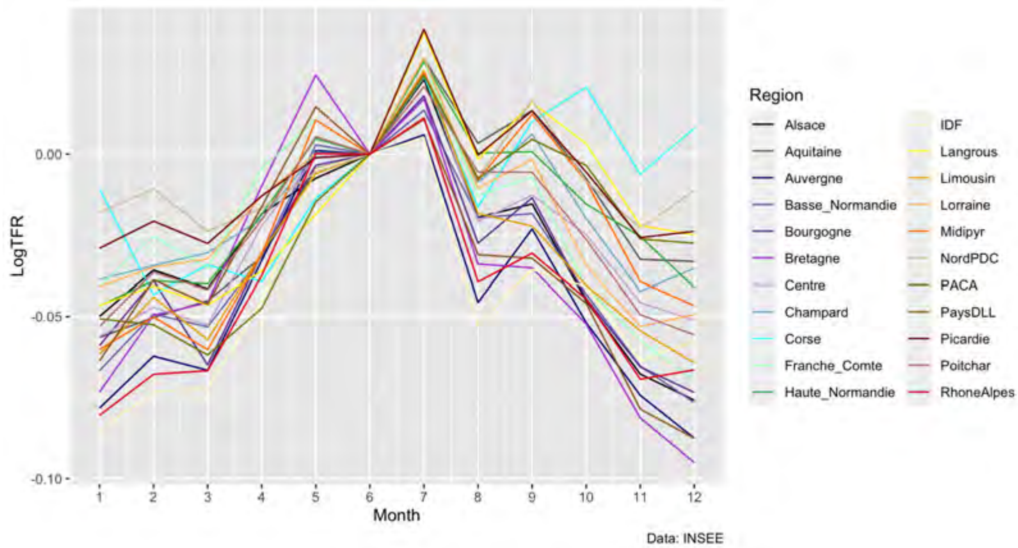

Figure 2.1: TFR Fluctuation by Region 1975-2020, Normalized to June (Month 06)

Refer to Section 3.1 for more information on TFR calculation technique.

to springtime births, particularly in the conception timing of the first child (Régnier-Loilier 2010). Overall, a peak of conceptions during the summer holidays, corresponding to a peak in birth rates in late spring was the dominant seasonal fertility dynamic in France through the 1980's (Leridon 1973). Through the 1990's the birth peak shifted later still into July, and in 2020 the peak in births is found between July and October (Papon 2020). Figure 2.1 displays the average seasonality of births by region for the window of this analysis (1975-2020). Over this window, the average seasonal peak of births may be observed around July.

Since the 1980's, there has been a decrease in the seasonality of births. Papon (2020) notes that in the 1970's, the birth peak represented a 10 percent departure from the rest of the year, whereas the birth peak of the 2010's is half the amplitude, representing a 5 percent departure from the rest of the year. Though many plausible hypotheses have been proposed to explain this change, among the most convincing is that a substantial amount of individuals underestimate how long it takes to conceive.

The time needed to conceive increases in relation to the age of the mother, and possible need for a doctor's intervention to remove birth control. Régnier-Loilier (2007) argues that in the face of unexpected delays, individuals may abandon previous seasonal preferences. Another reason for this decrease in seasonality is the decline of the institution of marriage, and related regimen of marital births (2010). Also in this work, Régnier-Loilier notes that, at the time of his writing, the remaining seasonal trend is a bump in births towards the end of September, corresponding to an increase in conceptions around the winter holidays, a trend also visible in other European countries.

According to Régnier-Loilier (Régnier-Loilier 2010) the decline of an important seasonal rhythm of births in France means that anomalous events have a more important role in the annual distribution of births than ever before. Heat waves are included in these anomalous events. Régnier-Loilier constructs a table of instances from 1975-2005 when seven consecutive days of birth rates fall outside the norm of the 4 surrounding years (the author acknowledges these cutoffs are arbitrary). Out of the 8 deficit periods observed, 3 were attributable to heat waves within the French territory occurring around 9 months prior to the birth deficit. Régnier-Loiler notes that to his knowledge, no prior attempt had been made to quantify this effect of heat waves on births in France.

In this same work, Régnier-Loilier proceeds to calculate the effect of heat waves on this birth deficit by comparing the anomaly month with the same month in surrounding years. Régnier-Loiler observes a decrease in births of 5 to 6 percent due to these heat waves. Régnier-Loilier also engages in a regional analysis, comparing mortality rates and birth gaps by region. He finds no correlation between the two phenomena, explaining that the incongruity likely comes from the simoultaneous connection between space and heat wave mortality, whereas a gap in births is only observable 9 months after the heat wave event. Heat waves often occur during the months of July and August, coinciding with *vacances*, a period of high internal migration within France. Therefore, individuals may have been exposed to the heat wave in a different region than they were several months later when the effect in regional fertility rates is observed. Due to data constraints, the wider literature on this subject is limited in addressing the role of spatial mobility within the effects of heat waves on fertility rates.

To conclude, given the decline of religiosity and advent of birth control, annual anomalies are now a key driver of the annual distribution of births in France. Climate change is causing heat waves that were considered anomalous in their severity to become the norm. Therefore, understanding the effects of heat waves in France is fundamental to explaining the current and future annual distribution of births. Yet, the citing articles of Régnier-Loilier's review contain no articles that further his heat wave analysis within the French context. The salience of this dynamic in shaping annual distributions of births in France add to the motivation this mémoire.

2.2.2 Regionality of Births in France

Sub-national dimensions of fertility rates are understudied in the European context due to uneven data availability compared to national level data (Buelens 2022). Yet, considering regional fertility rates together with the more common national approach has several advantages. First, regional fertility rates reveal to what extent national aggregations accurately represent the fertility dynamics within a country. European countries often hold significant heterogeneity in fertility rate dynamics, particularly between urban and rural regions. National fertility data, therefore, may shroud disparate fertility regimes within a given country (Buelens 2022; Boyle 2003). Second, even though the disparities of within-country fertility are smaller than the differences between European countries, within-country fertility differences have proven to be relatively persistent over time, despite predictions that EU integration would mute these differences (Boyle 2003). Specifically, Buelens (Buelens 2022, pp. 9) calculates that "heterogeneity between European regions only decreased by a fifth compared to its 1960 level." Therefore, that this mémoire is able to decompose the effects of heat on fertility rates to the regional level permits observation of any regional heterogeneity in the relationship between heat and fertility in France, which must be understood in the context of existing differences in fertility regimes and climates in the French context.

Next, I explain these regional differences in fertility rates in France, and how they have evolved over time. At the national level, France has seen a significant fall in the total fertility rate from almost 3 children per woman in 1960 to just below 2 children in 1975. Fertility rates then gently declined to around 1.6 in the 1990's, before reversing direction and hitting a recent high of around 2 children per woman in 2010, before descending again slowly, and then sharply due to COVID (INSEE 2024b). The dramatic decrease has not ceased despite the abatement of the pandemic. This overarching trend, however, has not occurred to the same extent across different regions.

Beginning in the 19th century when reliable regional statistics were first available, the northern portion of France held fertility rates that were more elevated than the rest of France. This area, surrounding but not including Île-de-France, was commonly referred to as the "fertile crescent" of France. The difference between this "fertile crescent" and the rest of France has been decreasing since the 1960s, for similar reasons that have decreased the seasonality of births in France: a rise in living standards in rural communities and the decreasing influence of religion within these rural communities (Desplanques 2011).

In Figure 2.2, I aggregate monthly total fertility rates into 5 year periods within the observational window of this study. I isolate the year of 2020 as their own period so that the effects of COVID are distinct from the period of 2015-2019.

The national decrease seen in the 1970's through the 1990's was driven by comparatively large decreases in rural communes compared to urban ones. As Figure 2.2 illustrates, from the period of 1975-1979 to the period of 1995-1999, we observe a decrease in TFR for most regions. This is most noticeable in very rural regions such

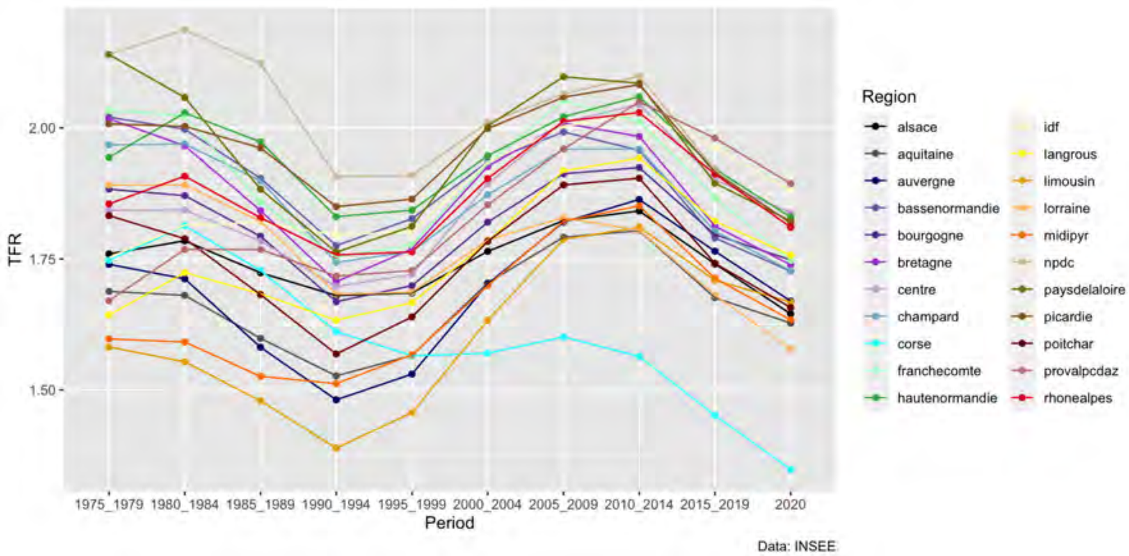

Figure 2.2: Period Fertility Rates by Region

Refer to Section 3.1 for more information on TFR calculation technique.

as Nord-Pas-de-Calais (tan) and Pays de la Loire (dark green), where fertility rates dropped by around 0.25 children per woman. In contrast, Île-de-France (pale yellow) during the same period remained more stable at around 1.8 children per woman.

Moving from the period of 1995-1999 until 2010-2014, most regions see a slight increase in TFR. The obvious outlier is Corse (light blue) where TFR remains stable during this period at around 1.6 children per woman. The urban-rural divide is visible during this period of TFR increase as well: several rural regions had faster TFR growth than the more stable TFR dynamic in Île-de-France. For instance, from 1995-1999 to 2010-2014, TFR increased in Île-de-France from 1.8 to 2.03: an increase of approximately 0.2 children per woman. The rural regions of Limousin (dark orange) and Auvergne (dark blue) saw increases in TFR of 0.35 and 0.33 children per woman, respectively over this same time period. This urban-rural divide is not uniform however, as northern rural regions such as Picardie and Nord-Pas-de-Calais saw smaller increases than Île-de-France, seeing an increase of 0.22 and 0.19 children

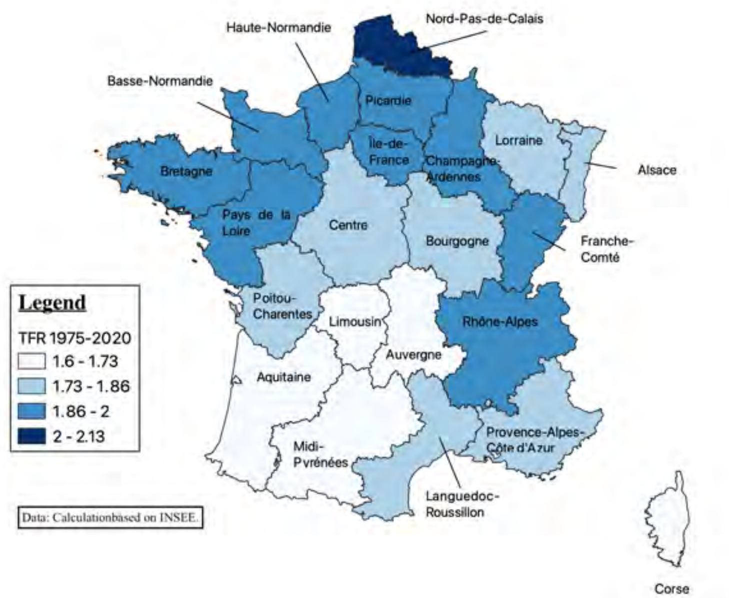

Figure 2.3: Total Fertility Rates by Region 1975-2020

Refer to Section 3.1 for more information on TFR calculation technique.

per woman respectively within this specific window.

The salient point from this period of TFR increase is that even if some rural regions saw a larger increase during this time, it was not enough to compensate for the precipitous decline in rural fertility rates seen in the first decades of the window of analysis. Hence, Île-de-France's higher fertility rate compared to some other regions in France is attributable to its lack of volatility compared to other regions. The importance of this dynamic is visible in Figure 2.3. Averaged over the entire period of analysis for this work, Île-de-France has a higher TFR than some of its rural neighbors, both at the French and the European scale (Buelens 2022). The literature on this subject offers many explanations for Île-de-France's outlier status.

These explanations involve both substantial differences in fertility behavior between the women in Île-de-France and elsewhere in France, and also technical differences in overall age structure which factor into fertility measures but may not necessarily indicate substantive differences in fertility per capita (refer to 3.1 for more information on the TFR calculation technique used in this analysis). One such technical difference is that Île-de-France tends to host a younger population than many more rural areas in France. Under such an age structure, childbearing-age women in a comparatively older province would need to have more children per capita to counteract previous losses in fertility that contributed to a lower number of childbearing-age women in the first place (this is another example of the the notion of demographic momentum discussed in the introduction). The regional TFR calculation technique used here takes into account the number of childbearing age women in each region (age 15-49), though not the number of women at each specific age within this range.

Moving on to substantial differences in fertility behaviors between Île-de-France and other regions, the are several possible explanations. Chief among these is that a higher number of foreign born women residing in Île-de-France relative to the provinces, who typically have more children than native born women (Desplanques 2011; Louchart 2021). Other possible explanations include differences in socioeconomic status concerning the population of Île-de-France with other regions. Previous research has shown that within the French context, women at either end of the income scale are more likely to have children than those in the middle of the income scale (Reynaud 2022). Furthermore, compared to other regions, Île-de-France hosts more individuals at either end of the income scale. The poverty rate in Île-de-France in 2020 was 15.5 percent, 0.7 percentage points higher than the national average (INSEE 2024a). Concurrently, Île-de-France also measures the highest median salary compared to all other French regions (24,490 euros per year compared to the national average of 22,320 euros per year) (INSEE 2024a). Therefore, it remains plausible that income inequalities within Île-de-France may factor into comparatively elevated fertility rates of Île-de-France as a whole.

Returning to the national picture, since the national peak in 2010, TFR trends have reversed themselves again, entering a period of decline. Louchart (2021) notes that fertility decline from 2010-2020 was ubiquitous in western countries due to the economic stress of the Great Recession of 2008. Yet, Louchart notes that this decline has persisted beyond the acute period of economic crisis, suggesting more fundamental economic and lifestyle factors that do not support having children in the past decade. This is consistent with the broader international trends in fertility decline as observed by Lesthaeghe (2010) and others. As in the earlier subperiods, the relative stability of the Île-de-France fertility rate is a key dynamic in the French subnational context. Louchart notes that from the period of 2010-2019, Île-de-France saw a 6 percent decline in total fertility rate, whereas the rest of the french regions saw a 13 percent decrease.

The period of 2020-2023 is obviously characterized by the effect of the COVID pandemic on fertility rates. With the onset of the pandemic, 2020 saw a decrease in fertility compared to the previous period that affected all regions relatively equally (Figure 2.1). Though we are not far removed from the pandemic, early evidence suggests that the abatement of the pandemic has not led to a consistent recovery of births. In fact, 2023 saw a dramatic decrease in the national fertility rates compared to 2022, from 1.79 to 1.68 children per woman. The decrease in fertility rate from 2022 to 2023 is almost triple the size of the decrease in fertility rate from 2021-2022 (0.04 decrease to a 0.11 decrease in children per woman), even though it is one year further removed from the pandemic. The decrease in births in 2023 has continued in the early months of 2024, and has been observed even in the typically stable Île-de-France (INSEE 2024b).

In past decades, French fertility rates, and consequently French welfare policies, have served as an exemplar in the EU context due to French fertility rates typically falling around the replacement rate of 2.1 children per woman. The reason for this dramatic decrease in French fertility rates in the past couple of years has not been definitively explained. It is likely that the same factors that have lowered fertility rates in other western countries have also permeated France: an uncertain economic landscape containing increasingly stratified labor and housing markets, together with cultural shifts such as increasing ecological concern and the postponement of family formation. The case of France, paired with similarly declining fertility rates in Nordic countries, suggest that a generous welfare state cannot completely compensate for these wider trends. Though this recent decrease in fertility rates is not included in the window of analysis here, it is still relevant to consider the current context of unprecedented decline when assessing the importance of further negative influences on fertility rates coming from heat shocks.

2.3 Climate and Climate Change in France

Having described underlying spatial and temporal trends in fertility rates, I now consider existing dynamics of another key variable in this work, the climate regime and behavior of hot weather in France within the period of analysis considered here.

The categorization of climates within metropolitan France can be done in several ways depending on the complexity of analysis. Méteo-France, for example, divides France into 5 climatic zones (Figure 2.4). Other geographers have proposed a 8 zone classification (Joly et al. 2010). No matter the classification, a disconnect between administrative regions and meteorological observations emerges. In several cases, a French administrative region may span several climate zones. Therefore, any attempt to harmonize these fuzzy climactic zones with administratively organized social data will be imperfect.

Here I elaborate on Méteo-France's climate classification for the sake of consistency with the meteorological data I consider in my analysis, which originally comes

Figure 2.4: Climates of France

from Méteo-France weather stations and is then distributed to the EU copernicus database. Figure 2.4 illustrates these climactic regions of France. First, there is the oceanic climate, encompassing all of Bretagne and the coastal portions of, from North to South: Nord-Pas-de-Calais, Haute and Basse Normandie, Pays de La Loire, Poitou-Charentes and Aquitaine. According to Méteo-France this climate is characterized by its mild temperature, mediated by the ocean, as well as its elevated rainfall compared to the rest of France. More inland there is the appearance of the altered oceanic climate, extending from Picardie and Champagne-Ardennes, through Île-de-France, Centre, Limousin, and the inland portions of Pays de La Loire, Poitou-Charentes and Aquitaine. The distance from the sea for these regions means that they do not benefit from the thermal regulation of the ocean. As a result, the temperature differences between seasons are more marked, and in the interest of this analysis summer heat waves historically are more severe than that of the oceanic climate. This is not unique to France: across the European continent, researchers have plotted the protective effect of maritime thermal regulation upon the severity of heat waves (Zschenderlein et al. 2019). The eastern border of France belongs to a semi-continental climate. In this analysis this pertains to the regions of Alsace, Franche-Comté, and the western portion of Lorraine. Similar to the altered oceanic climate, summer temperatures of this part of France are elevated due to the lack of oceanic thermal regulation. Next, there is the mountainous climate, including portions of Auvergne, Rhône-Alpes, Franche-Comté in the East, and in the South, the portions of Languedoc-Roussillon, Midi-Pyrénées and Aquitaine that border the Pyrénées mountain range. The microclimate fostered by these mountain ranges contributes to a high degree of cloud cover during the summer months, which is typically protective of extreme heat. Finally, there is the Mediterranean climate which is characterized by hot summers, but also high winds (Météo-France 2023b).

The overarching climates of these regions is important to take into account because they mediate the distribution of hot days in the first several decades of the window of analysis. However, climate change is causing not just the random probability of an errant hot day to increase. Instead, climate change is contributing to fundamental changes in atmospheric dynamics and land/atmosphere interactions that are changing the behavior of hot weather. Hot weather is increasingly defined as the occurrence of extended, severe heat and not simply a day or two of warm temperatures.

To explain the causes of these extended periods of heat, I here summarize the literature on this subject from the field of planetary science. White et al. (2022) states that there are two systems through which planetary scientists commonly understand climate change: thermodynamic and atmospheric. Thermodynamics are the primary driver for global trends in earth's surface temperature. White et al. (2022) and Shepherd (Oct. 2014) summarize that climate science research has generated much more certain findings considering the causes and effects of this thermodynamic response on global surface temperature increase and consequent sea level rise. Shepherd (Oct. 2014) comments that "nearly everything we have any confidence in when it comes to climate change is related to global patterns of surface temperature, which are primarily controlled by thermodynamics. In contrast, we have much less confidence in atmospheric circulation aspects of climate change, which are primarily controlled by dynamics and exert a strong control on regional climate." Yet, there is emerging evidence that atmospheric dynamics are decisive in shaping the stifling "heat dome" conditions like those seen in Europe in 2003, and that these anomalous atmospheric dynamics are becoming more frequent with climate change.

The basic mechanism for how atmospheric dynamics contribute to especially severe heat waves is as follows. There are many currents and waves at each level of the atmosphere that contribute to the weather we observe each day. One such phenomenon are called Rossby waves- waves in the flow of atmospheric jets in the lower levels of our atmosphere (Oxford Reference n.d.; White et al. 2022). Typically, these waves are transient. Sometimes they may become stationary (for reasons that are not perfectly defined by the scientific literature yet), with significant effects on regional meteorology. White et al. (2022) summarizes that "these quasi-stationary waves remain in approximately the same location with approximately the same phase for several days to weeks; this can lead to extreme events such as multiple days of rainfall

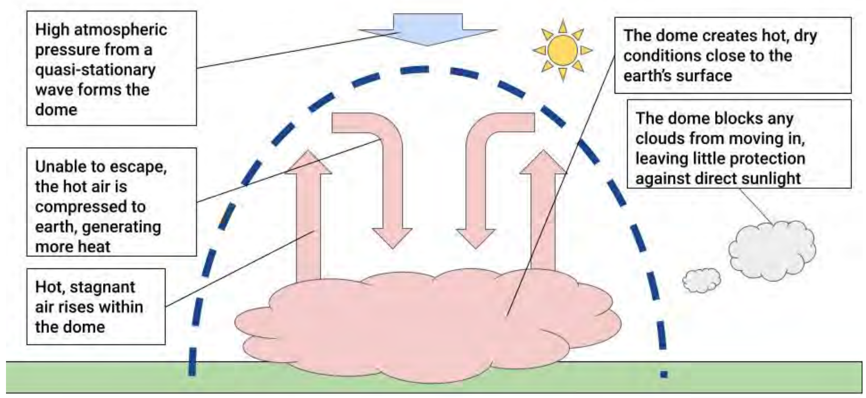

Figure 2.5: Heat Dome Mechanism

leading to flooding, or extended heatwaves." A key example of such an event, cited throughout the scientific literature on the subject, is the 2003 European heat wave e.g. (Petoukhov et al. 2013; Jiménez-Esteve, Kornhuber, and Domeisen 2022). The occurrence of a Rossby wave becoming a quasi-stationary wave contributes to meteorological conditions dubbed in popular media as a "heat dome" or "anti-cyclone." Figure 2.5, adapted and translated from Météo-France, illustrates the effects of a heat dome.

A heat dome prompts several concurrent meteorological conditions besides high daily temperatures. These conditions include elevated nighttime temperatures, due to the persistence of hot air within the dome (Météo-France 2023c). The literature on heat and mortality has consistently shown that high daytime temperatures are not a sufficient cause for a massive number of heat wave deaths. Instead, persistently elevated nighttime temperatures play a decisive role in turning a heat event into a high morbidity and mortality event, because individuals do not receive a respite from the physiological effort their bodies must exert in order to compensate for the high daily temperatures e.g. (Laaidi et al. 2012). The heat dome effect also prevents cloud cover, precipitation, and wind from entering the area, all of which

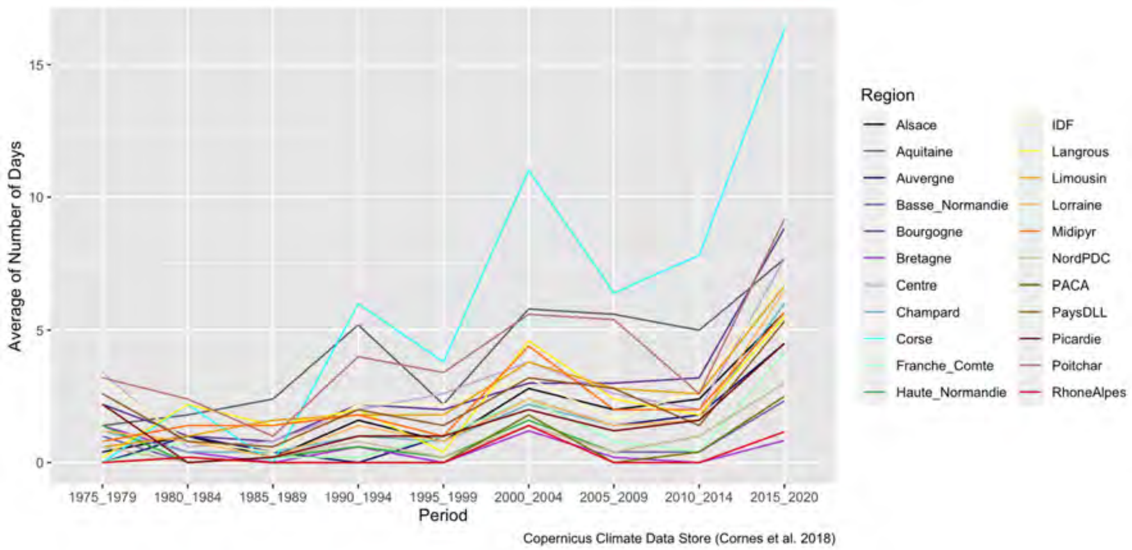

Figure 2.6: Yearly Number of Days above 25 C by Period Average and Region

have cooling properties even on hot days (Météo-France 2023c). The lack ventilation within the heat dome also means air pollution is trapped within the system, which in some cases may exacerbate poor health outcomes associated with heat, as has been found regarding sperm production (Kumar and Singh 2022). Because heat domes have several meteorological traits that pose risks for human health, Météo-France distinguishes between heat waves, meaning 3 or more days of heat in a row and one or two days of hot temperatures, labelled instead a "pic de chaleur" (Météo-France 2023a).

The concrete differences between an errant hot day and a hot day that is a symptom of a heat dome event informs the following hypothesis to be tested in the later analysis: **the effect of heat on fertility will be larger from hot days within a heat wave event than outside of one (H4).** The importance of testing this hypothesis is further supported by evidence that hot days both inside and outside of heat dome events are becoming more frequent over time, and thus are a key to assessing the future implications of this research.

In Figure 2.6 I display the number of days above 25 C per region per year within the meteorological data used in this analysis. I use mean daily temperature since it accounts for both the day time high and nighttime low temperature. The same logic is present in my subsequent analysis and in the heat/fertility literature at large. I use 25 C as a threshold to match the threshold for the highest temperature interval in my analysis (for more information on the threshold selection refer to section 3.3). In Figure 2.6 we see a general increase in the number of days with a mean temperature above 25 C across regions from the beginning to the end of the period of analysis. Periods of note include that of 2000-2004, in which the count of hot days from the heat wave of August 2003 are visible. Also important is the most recent period, 2015-2020, which saw a marked increase across all regions compared to the period prior.

There is some emerging evidence that the behaviors of stationary waves, as well as other planetary dynamics such as land/air feedback loops (Tuel and Eltahir 2021), are shifting due to climate change and will consequently mean an increasing amount not only of hot days overall, but also hot days within heat dome events (White et al. 2022). According to Météo-France "No matter the scenario regarding the emission of greenhouse gasses, global warming will continue for several decades... The frequency of these events [in France] may double from now to 2050. By the end of the century the may be much more severe and long, occurring in a period between the end of May and the beginning of October" (Météo-France 2023d).

In Figure 2.7, I plot the number of heat wave like days per region per year within the meteorological data used in this analysis, viewed within a period average. Following the example of the national benchmark, I count "heat wave" days as days where the mean 24 hour temperature is above 25 C, *and* the previous two or more days also had a mean temperature above 25 C. Since the Météo-France national benchmark for a heat wave is three days in a row of the mean temperature above 25.3 C, this figure is somewhat comparable to the national benchmark.

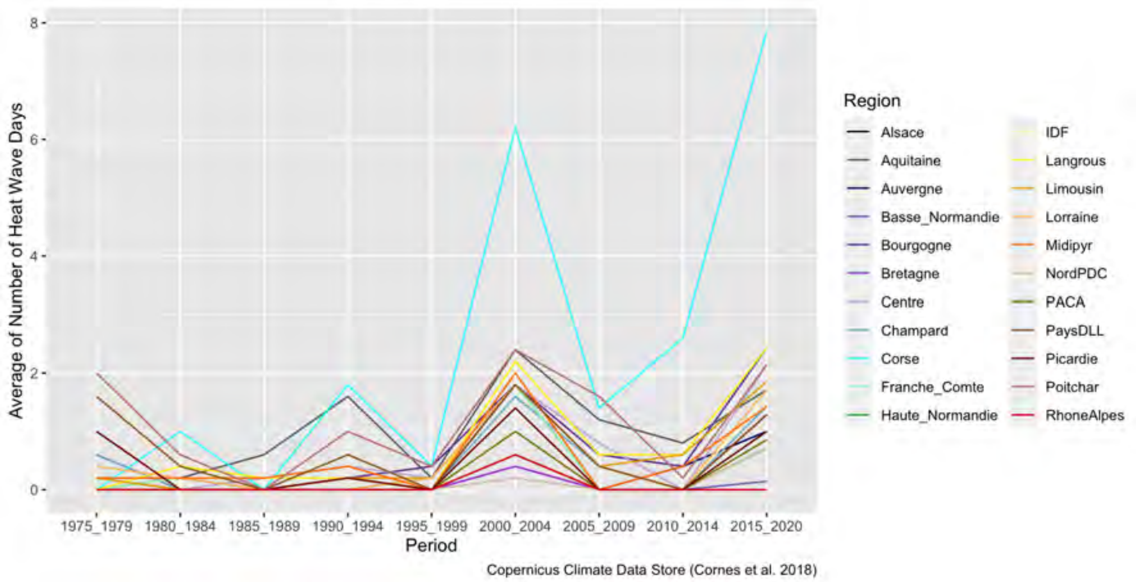

Figure 2.7: Yearly Number of Heat Wave Days by Period Average and Region

Figure 2.7 illustrates that for most of the window of study, the majority of regions had less than one heat wave day per year when averaged to a period, with the heat wave of 2003 existing as an anomaly across all regions. The most recent period, 2015-2020, saw a change across all regions to an average of more than one heat wave day per year as a period average.

Because the mechanisms of heat domes are still under an active state of research within the field of atmospheric science, there is a high degree of uncertainty when predicting where exactly the heat domes will increase the most as the area of inquiry becomes smaller (White et al. 2022). This means subsequent analysis relating these events to fertility rates cannot definitively say which regions are the most at risk to have their fertility rates further affected by such heat waves. Due to the complexity of such earth/air systems, the future spatial distribution of heat events cannot be perfectly modelled.

Recent anecdotal evidence, however, suggests that many regions may eventually be susceptible to this risk. For example, Bretagne is the only region entirely included in France's oceanic climate. As discussed previously, the historical regime of an oceanic climate includes a protective effect from extreme heat due to the thermal regulation from the ocean. Yet, in recent years, Bretagne has seen heat waves that are unprecedented in recent memory. In July 2022, a heat wave caused 4 departments within Bretagne to measure their hottest ever recorded temperatures, and for the first time ever these departments were included in Météo-France's "vigilance rouge canicule"- the highest level of national heat wave classification (Météo-France 2022). The recency of this event means it falls just outside the window of analysis of this study. Nevertheless, it illustrates that past climactic behavior is not a perfect predictor of future climactic behavior, even when comparing data from a few years ago.

2.4 Heat and Fertility: Medical and Demographic Findings

Having reviewed trends in both fertility rates and hot weather in France, I now turn to relevant medical and demographic literature which has explored the connection between the two. Kumar and Singh (2022) conduct a review on the state of research concerning environmental factors on semen quality and male fertility. They note that summer heat often act as a double hazard to sperm quality, due to a) high levels of pollutants such as sulfur dioxide and nitrogen dioxide that have particularly negative effects at the first stages of spermatogenesis, and b) heat, as they note that scrotal temperatures elevated by 1.5 C is enough to disrupt sperm production.

There are three avenues through which female fertility may be negatively affected by heat. First, there is some emerging evidence that heat exposure interrupts female gametogenesis (S. Kulkarni and K. Kulkarni 2023), though since research on the effect of heat on female gametogeneis is less advanced than male gametogenesis (spermatogenesis) the heat/fertility literature is concentrated on the disruption of

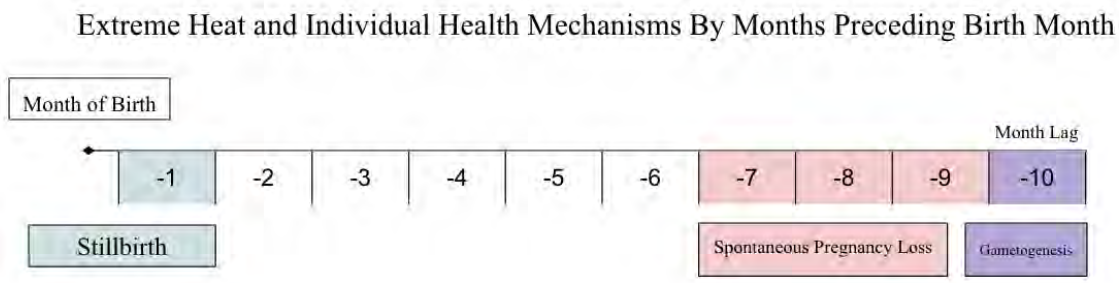

Figure 2.8: Diagram of Mechanisms

male gametogenesis. Second, extreme heat may increase risk of spontaneous abortion for women in the first trimester of pregnancy (T. Hajdu and G. Hajdu 2023). Third, there is substantial evidence that extreme heat exposure in the week before delivery increases the risk of stillbirth (Kanner et al. 2020; McElroy et al. 2022). Therefore, there are several months, lagged from birth, where heat may affect fertility rates. The timing of these effects are illustrated in Figure 2.8.

A negative effect on fertility rates from heat observed one month prior to the birth month signifies the mechanism of stillbirth. A negative effect on fertility rates from heat 7 or 8 months prior to the month observed points to spontaneous pregnancy loss as an explanation. Finally, a negative effect on fertility rates 9 or 10 months after a period of heat suggests slowed gametogenesis as a mechanism. It is also possible that extreme heat decreases sexual activity. The spermatogenesis mechanism hypothesis, however, is more in favor in the heat/fertility literature for the following reasons. First, though there are few studies that directly focus on the effect of heat on sexual behavior, those who have do not find a firm relationship between the two (T. Hajdu and G. Hajdu 2019; Wilde, Apouey, and Jung 2017). Second, that the effect is visible at both a nine *and* a ten month lag across the recent heat/fertility literature lends support to a biological, rather than behavioral response to extreme heat. I will return to this point in discussing my results in Section 4.2.

Barreca et. al. (2018) was one of the first works by social scientists to systematically explore the link between heat and fertility. Notable predecessors include the Lam and Miron (1991; 1996), Lam et al. (1994) and Seiver (1985; 1989), analyzing the case of the US. Barreca et al. make several important improvements compared to this early work. These prior studies apply their estimation strategy to each state separately, and prescribe either linear or quadratic functional forms on the relationship between heat and fertility. To address these weaknesses, Barreca et al. employ an estimation technique that divides daily temperature into bins, which permits for the possibility of a nonlinear effect shape. This work also tests larger series of lags than these previous studies to observe the possibility of a short term catch-up in births following the negative shock from extreme heat. Furthermore, Barreca et al. propose a series of fixed effects to account for underlying trends in fertility and weather that have since become standard in current literature. With this methodology, Barreca et al. find that the negative effects of heat on fertility observed at an individual level by the medical literature is visible at population level in the US.

Since then, similar studies have confirmed these findings in South Korea (Cho 2020), Hungary (T. Hajdu and G. Hajdu 2022), Brazil (Marteleto, Maia, and Rodrigues 2023), and Spain (Conte Keivabu, Cozzani, and Wilde 2023). Similar studies focused on developing countries have evoked similar findings, though due to data constrains in national registry data, the estimation techniques differ somewhat from the studies listed above (Grace 2017; Geruso, LoPalo, and Spears 2021; Gray and Thiede 2024).

On France, Régnier-Loilier (2010) discusses the effect of heat waves on fertility rates in France within an article on birth seasonality. He estimates a 5 to 6 percent decline in fertility rates at the national level following heat waves by comparing heat wave affected years with their surrounding years. This work could be built upon by employing the fixed-effects approach that has emerged since the publishing of Régnier-Loilier's work. Furthermore, the estimation technique used in this mémoire, by the inclusion of a large series of lags permits a more substantial discussion of biological mechanisms and catch-up effects than is the case in earlier methods. Despite ample data, there have been no studies on France comparable in to the ones listed above published between 2020-2023. Considering that the relationship of heat and fertility has been observed in a relatively diverse group of countries, and that an earlier findings by Régnier-Loilier (2010) gesture to the same dynamic being present in France, I form here my primary hypothesis: **heat waves have a negative effect on fertility rates in France (H1)**.

There are several open questions in this stream of research. First, there is no agreement on which mechanisms explain this effect. The main explanation, proposed by Barreca et al. (2018), is that a decline in sperm quality following hot weather explains declines in fertility rates. A strength of the work by Barreca et al. is their use of weekly fertility data, which allows them to note a two week "latent effect on conception chances, which is more easily explained by a decline in reproductive health as opposed to some delayed effect on sexual activity" (A. Barreca, Deschenes, and Guldi 2018). Other possible mechanisms include an increase in spontaneous pregnancy loss during heat waves due to increased stress on the body of the mother, compounded with the added flux of patients in healthcare infrastructure (Marteleto, Maia, and Rodrigues 2023).

There are also open questions in this literature about methodology. First, this body of literature does not have a standard measure of a "hot" day. For example, Conte Keivabu et al. (2023) call days with a mean temperature over 32°C (89.6°F) as "hot/extremely hot". Barreca et al. (2018) defines days with a mean temperature of 80°F (27°C) as "very hot", and Hajdu and Hajdu (2022) consider "hot" days when the mean temperature is over 25°C (77°F). In all of these cases, a day is defined as its full 24-hour period. This is so the measure encompasses the daytime high, as well as the nighttime minimum temperature. Marteleto et al. (2023) classifies extreme heat relative to a historical benchmark of a 30-year monthly mean prior to the window of study for each region.

Additionally, there are also no strict procedures regarding the construction of temperature as a variable. Most studies sort daily or month temperature into bins, but the intervals of these bins vary between 5-10 degrees (F) depending on the study. All these differences between studies limit comparability across country contexts. Moreover, justification is not always given in these studies for these diverging methodological choices. In order to contribute to this literature, my mémoire will compare the outcomes of several different operationalizations concerning the same data: temperature bins, a monthly historical benchmark, and a the effects of consecutive hot days. Still, given that this literature has still arrived at similar findings across differing country contexts and methodological choices, I form the following hypothesis to be tested in my analysis: **Different operational definitions of extreme heat will still yield similar results (H5).**

So far, I have discussed the two key variables of this mémoire: the independent variable of heat, and the dependent variable of fertility rates. I have also discussed the possible mechanisms through which the two may be connected. I now discuss potential moderators in the heat/fertility relationship. Here, I focus on two potential moderators that have been identified by sociological literature on heat waves and more proximate heat/fertility research: public policy and air conditioning adoption.

2.5 Potential Moderators: Policy and Air Conditioning

2.5.1 Heat Wave Public Policy

The work of sociologists of risk such as Ulrich Beck and Anthony Giddens has demonstrated that climate hazards must be understood in tandem with the role of the state in mediating such risks. Therefore, this section will describe how, internationally and in France, how heat waves have been defined. This serves to enrich the discussion in the proximate literature I review in the previous section on how to operationally define heat waves, as the academic literature has not engaged in this issue in a perfect intellectual vacuum, but in conversation with the thresholds developed by state meteorological agencies which posses significant control over the production of meteorological data that social science research relies on. Second, this section will consider how heat wave policy responses have evolved over time. Since the window of analysis of this mémoire (1975-2020) is large enough to encompass the development and implementation of iterations of public policies, these must be considered in subsequent analysis

Beginning at the international level, the IPCC defines a heat wave as "a period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves and warm spells have various and, in some cases, overlapping definitions" (IPCC 2022). The World Meteorological Organization, also vaguely defines a heat wave as "a period of marked and unusually hot weather persisting for at least two consecutive days" (WMO 2023). Since there are no specific benchmarks given at the international level, national governments and individual researchers have been left to choose their own definition for heat waves, resulting in inconsistent operational definitions of extreme heat within the literature on the health effects of heat.

Given that there is no international standard of extreme heat on which to base the analysis of this mémoire, the next logical step is to examine the definitions of extreme heat that exist within the French context, and any related policies that could conceivably affect the evolution of the heat/fertility relationship in France between 1975 and 2020.

Prior to the 2003 heat wave, France had known only two comparable events in recent memory: heat waves in 1976 and 1983. Consequently, extreme heat was thought of in popular consciousness and public policy as a mere nuisance- a temporary discomfort rather than a serious threat to public health (Keller 2015). This was to change permanently in the first weeks of August 2003, as an unprecedented heat dome settled above Western Europe. Temperatures soared to over 35 degrees across France, and remained elevated during the night. As the hot days continued, the heat wave transformed into a mass mortality event. The French public authorities, with little experience in this type of disaster, were slow to respond, despite physicians reporting overflowing hospitals and morgues. The full death toll would only be known in the months and years that followed. Depending on the estimates, around 15,000 people lost their lives in France due to the 2003 heat wave (Keller 2015).

Faced with the fatal consequences of a heatwave resulting from a policy vacuum on this hazard, in the immediate wake of the 2003 heat wave the French national government implemented a tiered heat wave alert system (or: système d'alerte canicule et santé: SACS). This alert system is rooted within the domain of Météo-France, who track rolling average temperatures for each region through their extensive network of weather stations (Santé Publique France 2023a). The logic of the thresholds, however, was built in conjunction with Sante Publique France, via a retrospective calculation beginning with surges in mortality and then examining which temperatures in each specific region appeared to trigger a meaningful increase in this measure. The heat wave alert system is based on four tiers, each with their own risk management elements, which are elaborated on in Figure 2.9, translated from Santé Publique France. (Santé Publique France 2023a). Other relevant responses not included here are labor protections, particularly for construction and other outdoor workers, linked to the upper levels of the heat alerty system (Ministère du Travail 2023).

This definition of extreme heat is specifically aimed at addressing the scenes of overflowing hospital hallways that percolated throughout the news coverage of the 2003 heat wave. This context is important, because the effects of heat on fertility may go unnoticed among those affected, and therefore there is much less motivation or base of knowledge for public authorities to build their thresholds around these less obvious health risks. Therefore, this analysis cannot only rely on the heat wave thresholds provided by the French government, as they are constructed to signify when heat causes severe morbidity or mortality among the population: temporary disruptions

Vigilance Level	Level of Heat Wave Plan	Meteorological Situation	Management and Prevention Measures
Green	Seasonal Level	Normal Temperatures	None
Yellow	Heat Warning	• Episode of Persistent Heat • "Pic de Chaleur" (Heat Spike)	Preventative Communication
Orange	Alert	• Biometeorological indicators are met • Aggravating factors: humidity, atypical timing, pollution	Communication, special plans in hospitals and nursing homes, helpline, assistance to those registered with town hall, outreach to homeless individuals. Management: Ministry of Health
Red	Maximum Mobilisation	• Extreme Heat Wave • Possibly accompanied by: drought, power outages, forest fires, significant health effects	Identical to Orange but reinforced. Management: Prime Minister

Figure 2.9: Système d'Alerte Canicule et Santé (Sacs): Heat Wave and Health Alert System

to spermatogenesis do not meet this criteria. Indeed, the core results of section 4 show that the effects of heat on fertility rates are statistically significant when the daily mean temperature is between 20 and 25 C: below the French national heatwave threshold of 25.3 C.

In 2023, the French ministry of Ecological Transition unveiled a "National Plan" to address heat wave risks. This national plan builds upon the heat wave alert system, which functions primarily for the benefit of public information. There are two reasons for this increase in policy interest in addressing heat waves. First, the decades since the 2003 heat wave have revealed that the 2003 heat wave marked the beginning of a "new normal", rather than a tragic anomaly. The summers following 2003 would continue to log heat waves within France, even if prior to 1989, they were observed only around once every five years. Second, the health risks of heat waves proved durable even after the lessons learned in 2003. A report from Santé Publique France found that 32,658 people in France had died from heat between the years of 2014 and 2022. Complicating typical narratives that only the elderly are seriously at risk from extreme heat, around a third of these fatalities were under 75 years old (Santé Publique France 2023b). The suite of policies proposed in the heat wave national plan encompass several sectors, including housing, transport, health, and labor, which is more comprehensive than the responses triggered within the original heat wave alert system. However, I will not delve into these policies because both the proposal and implementation of these policies falls outside the window of analysis of this mémoire.

The key point here is that from 2003-2020 (the period of analysis under the first set of policy responses), heat waves in France steadily increased in strength and number, and the first iteration of policy responses in light of the 2003 heat wave did not drastically reduce mortality. This gap led to a new iteration of more expansive policies from the French national government that were both announced and implemented after the window of analysis of this study. In my review of the policy documents most relevant to heat wave policy between 2003-2020, I found no mention of the potential effects of heat on couples that may be aiming to conceive a child. Only in policy documents and public information campaigns from the past couple years are pregnant women mentioned as an at risk group. Given how recently the academic literature has emerged around this issue, it is reasonable to assume that policymakers may not have known to specifically address the effects of heat on fertility.

Therefore, it is not possible to conclude, a priori, what effects, if any, these policies from 2003-2020 may have had on mitigating the effects of extreme heat on fertility. Two contrary, but plausible hypotheses emerge. One is that if the heat wave alert system during 2003-2020 was not able to resoundingly achieve its chief policy goal of reducing mortality, this does not inspire confidence in this policy's ability to address health risks that were not explicitly included in the aims of the policy. Yet, one could counter that these policies, combined with a heightened public awareness of the general risks heat waves pose after the shock of 2003, may have had a latent, mitigating effect on the consequences of heat on fertility due to individual coping mechanisms. This second hypothesis is further supported when we considered that heat mortality policies often target old and/or disabled people, and the population concerned with heats effect on fertility are more likely to be young and able bodied. This distinction, along with an increased prevalence of air conditioning in France over the window of analysis that I discuss in the next section, forms the foundation of another hypothesis for this analysis: **The effect of heat on fertility rates will decrease over time (H2)**.

2.5.2 Air Conditioning

Though the use air conditioning (AC) is not an explicit public policy in the French context, AC adoption is one of the most significant adaptive responses to heat shocks both in Europe and globally, since it is both highly effective and highly emissions intensive. Furthermore, previous studies on the heat/fertility relationship have provided convincing evidence on the role of AC adoption in mediating the temporal evolution of the heat/fertility effect magnitude over time (A. Barreca, Deschenes, and Guldi 2018).

At this point, I qualify this discussion of AC as an adaptive mechanism. AC has several negative externalities. AC consumes significant amounts of energy, placing stress on electricity grids when an entire city turns on its air conditioners. Furthermore, AC units have a two way effect on global warming: 1) from the emissions resulting from its electricity consumption, and 2) from the release of refrigerant gasses that are 12,000 to 14,800 times more effective at trapping heat than CO2 (UNEP n.d.). Global increase in demand for AC has led some researchers to forecast that these gasses will represent a significant driver of global warming in coming decades (Sovacool et al. 2021; Gschrey et al. 2011). Also important is that AC units do not make hot air disappear: they simply displace it. When AC units pump out hot air from homes and businesses, they displace it to outside the building. This is especially important in urban environments, where a street full of AC units contributes to the urban heat island effect and creates a self-perpetuating cycle for more cooling needs (Salamanca et al. 2014). For these reasons, the description here of AC as an

Zone	AC Penetration
H1A	17 %
H1B	31 %
H1C	28 %
H2A	11 %
H2B	24 %
H2C	32 %
H2D	41 %
H3	47 %
France	25 %

Table 2.1: AC Penetration by Zone. Data: ADEME

adaptive technology should not be seen as a perfect policy prescription; the negative externalities of widespread AC use are at once underestimated and difficult to quantify (Sovacool et al. 2021).

I continue now to describing the increase in prevalence of air conditioning in the French context within the period of study. Here, I rely mainly on ADEME's 2020 report entitled "Climatisation de Confort dans Les Batiments Residentiels et Tertiares." Concerning the evolution of AC adopting in France over time, ADEME has also observed an uptick in the past 5 years in consumer interest in AC units, as well as a surge in purchases directly following the 2003 heat wave (ADEME 2021, pp. 22, 24). They report regional distribution of AC within climactic boundaries used by energy companies to define the energy use of buildings within these regions based on climate and housing quality (replicated in Table 2.1). These results are based on a survey of 800 households with a representative spatial distribution. This report finds that the Northwest of France (Bretagne and Normandie) has the lowest rates of AC penetration across all of France, below 20 percent. The rates rise steadily moving South, with the region with the highest AC penetration rate here containing portions of Languedoc-Roussillon, Provence-Alpes-Côte-d'Azur and Corse (upwards of 40 percent) (ADEME 2021, pp. 16, 28).

The regional boundaries used by ADEME (Figure 2.10) deviate somewhat from the

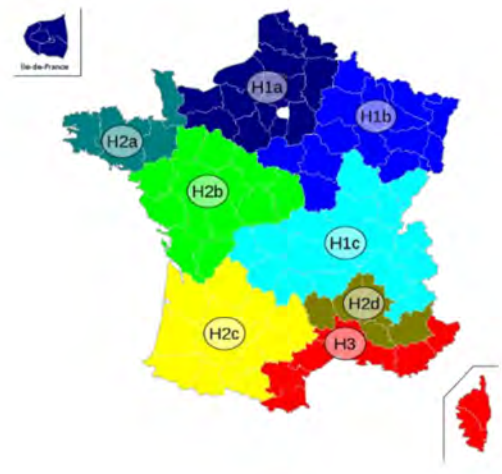

Figure 2.10: Zones used by ADEME

overarching regional boundaries used in this mémoire, and I take this into account in discussing the overlaps between these facts and the regional results of this work. Nevertheless, these discrepancies in AC penetration rates between the north and the south of France forms the basis of another hypothesis for this analysis: **Colder regions of France are more vulnerable to the effects of heat on fertility than warmer ones (H3)**. In testing this hypothesis I remain agnostic on the causal mechanism that could explain such a discrepancy: while the importance of air conditioning in moderating the heat/fertility relationship has some evidence in previous literature, I also accept that the geographic disparities AC adoption may very well be correlated with a variety of adaptive mechanisms and behaviours.

2.6 Hypotheses

Given the existing literature and the data available for this analysis, I will seek to test the following hypotheses.

H1: Heat waves have a negative effect on fertility rates in France.

Even though there exists only a handful of studies to make use of fixed effects in estimating the effect of heat and fertility, that the effect has indeed been observed in a variety of country contexts suggests we are likely to observe the same dynamic in France.

H2: The effect of heat on fertility will decrease over time

While the effect of heat on fertility has not received much policy attention within the window of analysis, it is possible that increasing rates of air conditioning adoption, as well as latent benefits to policies such as heat wave warning systems may have some effect on mitigating the effect of heat on fertility over time.

H3: Colder regions of France are more vulnerable to the effects of heat on fertility than warmer ones.

That colder regions of a given country are more vulnerable to heat shocks has been observed in literature concerning a variety of adverse health effects. Emerging evidence shows that the same regional discrepancies are visible concerning the relationship between heat and fertility, and I expect France to follow this pattern.

H4: The effect of heat on fertility will be larger from hot days within a heat wave event than outside of one.

Consecutive hot days often signify the presence of a heat dome event, which carries several significant risks over as isolated hot day.

H5: Different operational definitions of extreme heat will still yield similar results.

Since the literature is fractured in this regard, I take the case of France as an occasion to test multiple definitions of extreme heat. However, the literature has found in different contexts, effects of similar magnitude based on different operational definitions. By incorporating several operationalizations, I ensure that the overall finding is robust to different, but valid, methodological choices.

Chapter 3

Data and Methods

3.1 Fertility Data

In demographic literature, it is much more common to collect and analyze data at the annual level than at the monthly level. Generally, demographers are most interested in describing persistent, long-term trends. Within the discipline, such trends in fertility are commonly understood via an indicator called Total Fertility Rate (TFR), which estimates the number of children a woman will have through the end of their reproductive years, given existing age specific fertility rates. The advantages of this measure over more simple metrics, such as number of births, is that it takes into account the overall age structure i.e. number of women in their childbearing years in a given area, and the completed fertility of each woman, which is particularly important for forecasting long-run population projections.

Typically, TFR is provided on an annual basis, which naturally aggregates the seasonal fluctuations in fertility behavior as described in section 2.2.1. Consequently, data Total Fertility Rate (TFR) on both a monthly and sub-national level is not commonly available in the European context. This data limitation means that literature on seasonal fluctuations in fertility has been confined to a handful of studies. In France, such research has been conducted only by researchers with access to INSEE data needed to calculate more granular TFR measures themselves (e.g. Régnier-Loilier at INED).

However, any analysis on the effects of transient exogenous shocks on demographic dynamics in the style of the New Climate-Economy Literature (Dell et al. 2014) requires such temporally and spatially granular TFR measures. Within the analysis of this mémoire, Total Fertility Rate (TFR) by month by region from 1975-2020 is calculated based on data requested from INSEE. This analysis is based on pre-2016 regional boundaries for the sake of data continuity. This refers to 22 regions in metropolitan France including Corse, and excluding the overseas departments (DOM), for the years of 1975-2020.

Based on data from INSEE that was requested in July 2023, TFR by month and region is calculated in the following way.[1] For every region at each month of the analysis, the calculation is based on three measures: the monthly number of live births (defined by by place of residence of the mother), the number of resident women aged 15-49, and the number of days in the month. That number of women and number of births is both based on residence of the mother ensures continuity over these measures, and controls for short-term migration of women at the moment of delivery, though inter-regional migration a few years before or after birth isn't captured here.

The first step includes dividing the number of women aged 15-49 by 35, in order to obtain the average number of women for each age within the range of 15 and 49 years old. We do not have data on the exact number of women at each age between 15-49, and only the total number within this age range.

[1] The team consists of Angela Greulich (CRIS) and Laurent Toulemon (INED)

The second step is to take the average number of live births per day, and divide this by the average number of women for each age within the range of 15 and 49 years old found in step one. This is then multiplied by 365.25 to obtain the monthly TFR. This takes into account the 28th of February every 4 years.

The third step is to harmonize this monthly TFR by region figure with the annual TFR by region published by INSEE. This is done by linearly extrapolating the 12 month average of the monthly TFR to equal the annual TFR for a given region. This aims to control for bias relating to the age structure of the population of each region

This measure of TFR for each region and month does not account for differences in age structure between regions regarding the population of women aged 15-49. As a consequence, simple comparison of this TFR between regions must be done with caution. For example, a higher TFR observed in Île-de-France may be a technical artifact rather than a substantial difference. That is, the elevated TFR in Île-de-France may be attributable to a higher number of women of childbearing age compared to more rural regions, rather than substantive differences in fertility behavior. Yet, this data still permits measurement of variation within regions under a fixed-effects methodology. It is a valid measure to distinguish fertility shocks lagged from extreme heat from the overarching time trends and seasonality of fertility rates within a given region, especially since the post-stratification by annual TFR aims to control for age structure bias.

3.2 Weather Data

Second, daily weather data for 1975-2020 is derived from the E-OBS daily gridded meteorological database distributed by the EU Copernicus Climate Data Store and compiled by Cornes et al. (2018). The use of this dataset is standard among both climatologists and social scientists in the European context. From this database I

Figure 3.1: Weather Stations

collect daily mean temperature, daily precipitation and daily relative humidity for the entire period of study. I divide daily mean temperature into a series of bins in order to facilitate interpretation on the hot days compared to other intervals (cf. Section 3.3). I include precipitation as a control as it is standard in the heat/fertility literature and wider literature concerning heat and social outcomes. Precipitation is included as a control since temperature and precipitation are often correlated, and omission of one when studying the other may lead to omitted variable bias (Dell, Jones, and Olken 2014). I also control for humidity given strong evidence in the wider literature on heat and health outcomes that high humidity increases the physiological burden of hot temperatures.

This information is collected through a rich network of in-situ weather stations and daily means are interpolated to display the data in the form of 0.1 degree cells. Figure 3.1 illustrates the location of the 1097 weather stations within France which serve as the foundation for the Copernicus data.

I use the R package ClimateExtract (Schmucki 2023) to extract mean daily tempera-

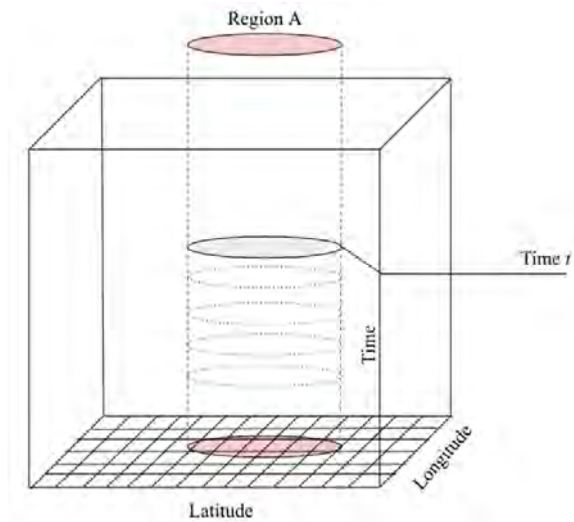

Figure 3.2: Structure and Manipulation of Copernicus Data

ture from the cells of the grid that falls within each regional boundary. Meteorological data is frequently stored in files with three dimensions: latitude, longitude, and time. This is in contrast with social science data which is usually organized across two dimensions. Therefore, the meteorological data most be decomposed and recomposed in a structure that is compatible with the structure of the TFR data and eventual panel data format.

For each region, the spatial extent for data extraction must be limited to the boundary given by Region A, and then decomposed into a two dimensional dataset composed of the meteorological variable for each region at a given year-month. By collecting meteorological data on a regional basis, I am able to test the third hypothesis of this mémoire: **colder regions of France are more vulnerable to the effects of heat on fertility than warmer ones (H3).** I illustrate the structure and subsequent manipulation of the meteorological data in Figure 3.2. Once this kind of dataset is produced for each region, it can be merged with its complementary fertility rates by a unique region/time identifier.

3.3 Methods

The methodology for estimating the effects of a variety of meteorological variables on social outcomes has been pioneered by a subfield of economics called the “New Climate-Economy Literature” (Dell, Jones, and Olken 2014). Techniques from this subfield have subsequently been folded into the quantitative wing of environmental sociology (Dunlap and Brulle 2015, Chapter 12). The research design of this mémoire rests upon specific practices and assumptions that characterize the “New Climate-Economy Literature” as defined by Dell et al. (Dell, Jones, and Olken 2014).

Specifically, it has become standard in existing heat/fertility literature to apply fixed-effects onto panel data (Dell, Jones, and Olken 2014; A. Barreca, Deschenes, and Guldi 2018; T. Hajdu and G. Hajdu 2022; Marteleto, Maia, and Rodrigues 2023; Conte Keivabu, Cozzani, and Wilde 2023; T. Hajdu 2024). This research stream has coalesced around the use of panel studies over cross sectional approaches, in order to leverage variation in extreme weather shocks over time within a given spatial extent, which forms the foundation of the causal claim within the heat/fertility literature and the broader ”New Climate-Economy” stream (Dell, Jones, and Olken 2014). The use of panel data is opposed to earlier studies in this field, which employed a cross-sectional approach. The cross-sectional approach has which has fallen out of favor compared to a panel approach since it is difficult to disentangle cross sectional differences in temperature and social outcomes with other long run historical trends. Fundamentally, the aim of this fixed-effects panel methodology is to view the effect of a climate shock outside of any omitted variables or pre-existing trends (Dell, Jones, and Olken 2014, pp. 744).

I use a fixed effects model estimated via OLS specified as:

$$]Y_{rt} = \sum_{j}^{J} \sum_{k}^{K} \beta T^{j}_{r,t-k} + \sum_{k}^{K} \gamma_k P_{r,t-k} + \sum_{k}^{K} \chi_k H_{r,t-k} + \alpha_{rm} + \delta_t + \theta_{ry} + (\Pi^1_{rm} \times t) + (\Pi^2_{rm} \times t^2) + \epsilon_{rt}$$

My dependent variable of interest is TFR, (Y) by region (r) at unique month-year (t). I perform a log transformation on this variable as is common in this literature, since it captures relative rather than absolute changes. My independent variable of interest is extreme heat. The norm in this literature is to sort daily mean temperature into a series of bins, effectively transforming temperature from a continuous to a categorical variable (Dell, Jones, and Olken 2014; A. Barreca, Deschenes, and Guldi 2018; T. Hajdu and G. Hajdu 2022; Cho 2020; Conte Keivabu, Cozzani, and Wilde 2023; T. Hajdu 2024). I include this in my model by the term T, which contains J temperature bins in region (r) from months t to k. The bins I construct, in degrees Celsius, are as follows: <0, [0,5), [5,10), [10,15), [15,20), [20, 25), >25. I take the bin of [10,15) as the omitted category. I construct the bins to be on the smaller end of what is found in the literature to receive more granular results. These benchmarks are most similar to Barreca et al. (2018) and Hajdu (2024). I calculate the days out of a given month and region where daily temperature falls within each bin, and apply this to each region at all unique year-months.

Upon first impression, a top temperature bin of >25 C may seem too low to capture "extreme" heat. Here, I stress that by using the 24-hour mean of a daily temperature, we capture both the daily high and nighttime low temperature, both significant to the physiological toll of extreme heat. Literature on heat and mortality has affirmed the decisiveness of nighttime temperatures in extreme heat events. Across age groups and geographies, morbidity and mortality rises during extreme heat events when temperatures remain high through the night, and individuals are subject to persistent heat stress (He et al. 2022; Murage, Hajat, and Kovats 2017).

Even if empirically using mean temperature has clear advantages, maximum temperature has a more intuitive quality, as it is this temperature we associate with the lived experience of "extreme" heat. To illustrate that days with a *mean* temperature above 25 C have a *maximum* temperature that is much higher, let us consider again the example of the 2003 heat wave. As temperatures started to rise the first week of August 2003, by August 9, 2003 the heat wave was around its peak. The mean temperature of this day in the region of Alsace was 27.6 degrees Celcius. The *maximum* temperature was 36.6 C. In Bourgogne the mean temperature was 28.4 C, the maximum was 38.6 C. In Aquitaine the mean temperature was 28.5 Celsius, the maximum was 37.2 (Cornes et al. 2018). These maximum temperatures in these regions across France clearly signal "extreme" heat for the area. As such, I extend this understanding a mean daily temperature of above 25 C, and use the results from this interval as a basis for testing the the first four hypotheses of this mémoire.

I also control for precipitation by constructing bins for daily total precipitation and including them in the model as a control variable under the term P. Since precipitation is included in this literature as a control, not a variable of interest, it is common practice to employ larger intervals than in the case of temperature. For example, Barreca et al. (A. Barreca, Deschenes, and Guldi 2018) includes a set of three precipitation bins, and Conte Keivabu et al. (Conte Keivabu, Cozzani, and Wilde 2023) simply include the monthly mean precipitation. Therefore, I consider daily precipitation assigned three bins: equal to 0, (0, 10), and equal or above 10 mm. An upper bin of 10 mm aligns with the work done by Hajdu (T. Hajdu 2024) in the case of Europe overall. I calculate the number of days in each month t-k for each region r that fall in each bin.

Similar to the debates on how to operationally define temperature within this literature, there is no consensus on how to operationally define humidity, or if to include it at all in the analysis. The literature on heat and mortality has firmly established the exacerbating role of humidity in the distribution of adverse health effects due to heat (A. I. Barreca 2012)). Yet, the heat and fertility literature does not uniformly include humidity within its framework of analysis. Important contributions in this regard were made by Barreca et al. (2018), who includes humidity only robustness checks due to differences in data quality between humidity and temperature, but nevertheless established humidity as a variable of interest within the heat/fertility literature. Conte Keivabu et al. (2023) also include humidity as a control, operationalizing it as the monthly average.

Most recently, the work of Hajdu (2024) featuring the entire European continent has gone the farthest in integrating the role of humidity within the heat/fertility relationship. Hajdu separates hot days into two groups: high and low humidity. He defines high-humidity hot days as having a relative humidity of above 60 percent, and with a mean temperature over a 24-hour period above 25 C. This temperature benchmark of 25 C is identical to the threshold I prescribed to the highest temperature bin in the previous section. However, it is not feasible to adopt the same humidity threshold that Hajdu adopts for the entire European continent for analysis on the French case. The daily relative humidity within each region studied here over the entire window analysis has a median of 81.1 percent humidity (mean: 79.2 percent humidity). Therefore, calling over 60 percent humidity "high humidity" within the French context would not be apt. Instead, I depart from the median humidity in France within the period of this study and construct three humidity bins along the intervals of <75, [75-85], and >85, in order to capture how many days in a given month were relatively low humidity, around median humidity, and relatively high humidity. These bins are featured over the entire range of lags (k), for each region and unique year-month ($H_{r,t-k}$)

I include temperature bin lags of -3 to 20 months (k=-3...20) in order to account for a dynamic relationship between temperatures across all the lag months for a given birth month. I also include three months of negative lag (or lead) as a placebo check, as temperatures observed after the month birth should not affect prior fertility rates (k=-1,-2,-3). The upper bound of 20 months allows for the observation of possible catch up effects, where individuals may compensate for a failure to conceive around the heat wave period with conception in the following months.

I then add several fixed effects that aim to account for the regional and spatial dynamics in fertility that I describe in section 2.2 in order to observe *uniquely* the effects of heat on fertility. First, region by month (α), which accounts for expected weather fluctuations or fluctuations in fertility behavior over the year in a given region. Second, year by month (δ), which controls for cycles encompassing all regions that affect fertility behavior such as the seasonality of marriage and birth month preference, which have been demonstrated to be relatively homogeneous at the national level (Régnier-Loilier 2010). This term also captures time-varying factors at the national scale that may affect fertility behavior such as economic or social changes. Third, I include region by year (θ), in order to eliminate any long term, coincidental changes in temperature and population dynamics, such as declines in fertility seen in many western countries coinciding with a general rise in temperature attributed to climate change.

Furthermore, I include a region by calendar month quadratic and linear time trend (π) to account for possible convergences in seasonality across regions over time. I cluster standard errors by region (ϵ). This is computed using the 'plm' package in R (Croissant and Millo 2018; Croissant and Millo 2008).

Finally, A methodological assumption of this mémoire borrowed from the "New Climate-Economy Literature" is the assumption that "climatic variables. . . are exogenously determined [and] reverse causation is unlikely to be a major concern." (Dell, Jones, and Olken 2014, pp. 743). Dell et al. further note that this assumption cannot be made universally, for example with the case of urban heat islands. Research within this field, carried out at the regional level, assumes that reverse causality, where social variables may feed back into weather, is negligible. I therefore make the same assumption within this mémoire.

Chapter 4

Results

4.1 Descriptive Statistics

Table 4.1 displays the average Total Fertility Rate and average number of days per month in each bin for each region over the entire window of analysis (1975-2020). Over the entire period of analysis, the TFR in France was 1.84 children per woman. The mean daily temperature was above 25 C for 0.17 days in an average month across all regions in the entire period. As discussed in Section 2.2, on average, within the window of analysis, Île-de-France and the northern regions of France (Basse-Normandie, Bretagne, Champagne-Ardennes, Haute-Normandie, Nord-Pas-de-Calais and Picardie) all have Total Fertility Rates above the national average for this time period (1.84 children per woman). Across all regions during this time period, around half of the days in an average month fell within the middle bins of between 5 and 10 Celcius, and the reference group of between 10 and 15 Celcius.

Table 4.1: Average TFR and Number of Days Per Bin by Region, 1975-2020

Region	TFR	<0	[0,5)	[5,10)	[10,15)	[15,20)	[20, 25)	>25
Alsace	1.75	2.891844	5.858156	6.629433	6.771277	5.914894	2.212766	0.1595745
Aquitaine	1.67	0.5070922	2.978723	7.769504	7.696809	7.515957	3.62234	0.3475177
Auvergne	1.69	2.001773	5.787234	7.51773	7.118794	5.952128	1.941489	0.1187943
Basse-Normandie	1.91	0.7570922	3.842199	8.828014	8.574468	7.120567	1.255319	0.06028369
Bourgogne	1.82	1.705674	4.87766	7.37766	6.916667	6.666667	2.643617	0.25
Bretagne	1.89	0.3705674	2.83156	8.824468	9.253546	7.812057	1.303191	0.04255319
Centre	1.86	1.095745	4.12766	7.822695	7.484043	7.25	2.41844	0.2393617
Champagne-Ardennes	1.88	1.925532	5.446809	7.319149	7.297872	6.409574	1.89539	0.143617
Corse	1.62	0.06560284	1.593972	8.617021	7.695035	6.964539	4.989362	0.5124113
Franche-Comté	1.92	2.943262	6.019504	6.75	6.840426	5.867021	1.921986	0.09574468
Haute-Normandie	1.95	1.076241	4.287234	8.503546	8.336879	6.810284	1.343972	0.07978723
Île-de-France	1.88	1.264184	4.43617	7.760638	7.452128	7.046099	2.258865	0.2198582
Languedoc-Roussillon	1.76	0.8120567	4.216312	8.20922	6.898936	6.569149	3.533688	0.1985816
Limousin	1.60	1.070922	4.445035	7.985816	7.455674	6.789007	2.47695	0.214539
Lorraine	1.82	2.514184	5.641844	6.900709	6.97695	6.136525	2.111702	0.1560284
Midi-Pyrénées	1.65	0.8492908	3.969858	8.246454	7.148936	6.824468	3.202128	0.1968085
Nord-Pas-de-Calais	2.13	1.33156	4.771277	8.347518	7.923759	6.675532	1.315603	0.07269504
Pays de la Loire	1.99	0.6542553	3.315603	8.099291	8.092199	7.751773	2.336879	0.1879433
Picardie	1.97	1.423759	4.829787	7.893617	7.780142	6.748227	1.632979	0.1294326
Poitou-Charentes	1.76	0.5673759	3.171986	7.560284	7.801418	7.781915	3.210993	0.3439716
Provence-Alpes-Côte d'Azur	1.83	1.453901	5.968085	7.524823	6.416667	6.370567	2.652482	0.05141844
Rhône-Alpes	1.88	3.225177	6.83156	6.943262	6.723404	5.384752	1.303191	0.02659574
ALL_FR	1.82	1.386686	4.511283	7.792311	7.484365	6.743714	2.344697	0.1748872

Data: INSEE and Copernicus Climate Data Store (Cornes et al. 2018)

4.2 Core Results

Figure 4.1 displays the effects of one day above 25°C compared to a day in the 10-15°C range on log TFR across lags from -3 to 20. Each circle denotes the point estimate, and the brackets signify +/- 2 standard deviations.

Here, we may assess the first hypothesis of this mémoire: **heat waves have a negative effect on fertility rates in France (H1)**. The results conveyed in Figures 4.1 and 4.2 confirm this hypothesis. Specifically, the model estimates that each day above 25°C is associated with a 0.260 and 0.256 percent decrease in fertility rates 9 and 10 months later, respectively. Following this shock, we do not observe any statistically significant positive rebound effect, suggesting that some portion of this negative shock results in a permanent loss of births.

That the effect is visible at 9 and 10 months is consistent with findings in the US (A. Barreca, Deschenes, and Guldi 2018), Spain (Conte Keivabu, Cozzani, and Wilde 2023), Europe (T. Hajdu 2024), South Korea (Cho 2020), Brazil (Marteleto, Maia, and Rodrigues 2023), and Hungary (T. Hajdu and G. Hajdu 2022). This finding also suggests that the most visible mechanism regarding the mechanism for the heat/fertility relationship is a decrease in conception probabilities. Earlier research by Barreca et al. (2018) and Hajdu and Hajdu (2022) that is able to capitalize on weekly fertility data has pinpointed that the effect is rooted in a negative change in conception probabilities around two weeks after a heat wave. They both conclude that this small lag matches with the effect that heat has on sperm quality, as sperm exposed to heat in the earlier stages of spermatogenesis will eventually be of lower quality at the peak of the sperm life cycle, about two weeks later. They also hypothesize that since the effect can be narrowed down to two weeks after the heat wave, a hypothesis on the role of changes in sexual behavior *during* the heat wave has less evidence than the spermatogenesis explanation.

Because this analysis is confined to monthly and not weekly data, I cannot definitively state if the effect seen here at 9 and 10 months comes from the spermatogenesis mechanism or a change in sexual behavior. Still, the spermatogenesis explanation appears more plausible for two reasons. First, the consistency of the mechanism seen across the literature where the data used allows a conclusion on this regard signifies that this finding is not an artifact of a particular country case. Second, that the effect seen here is of similar amplitude at both 9 and 10 months is more easily explained by the spermatogenesis mechanism than the sexual behavior mechanism. We may hypothesize, given a two week lag, that a heat wave appearing in the earliest portion of a given month would lead to a decrease in sperm quality in that same month and would therefore be observable in fertility rates within nine months. On the contrary, a heat wave appearing in the latter portion of a given month would contribute to a decrease in sperm quality in the next month due to the two week lag, and this morbidity would be observable in fertility rates nine months after this *following* month, for an ultimate lag of 10 months from when the heat shock was recorded.

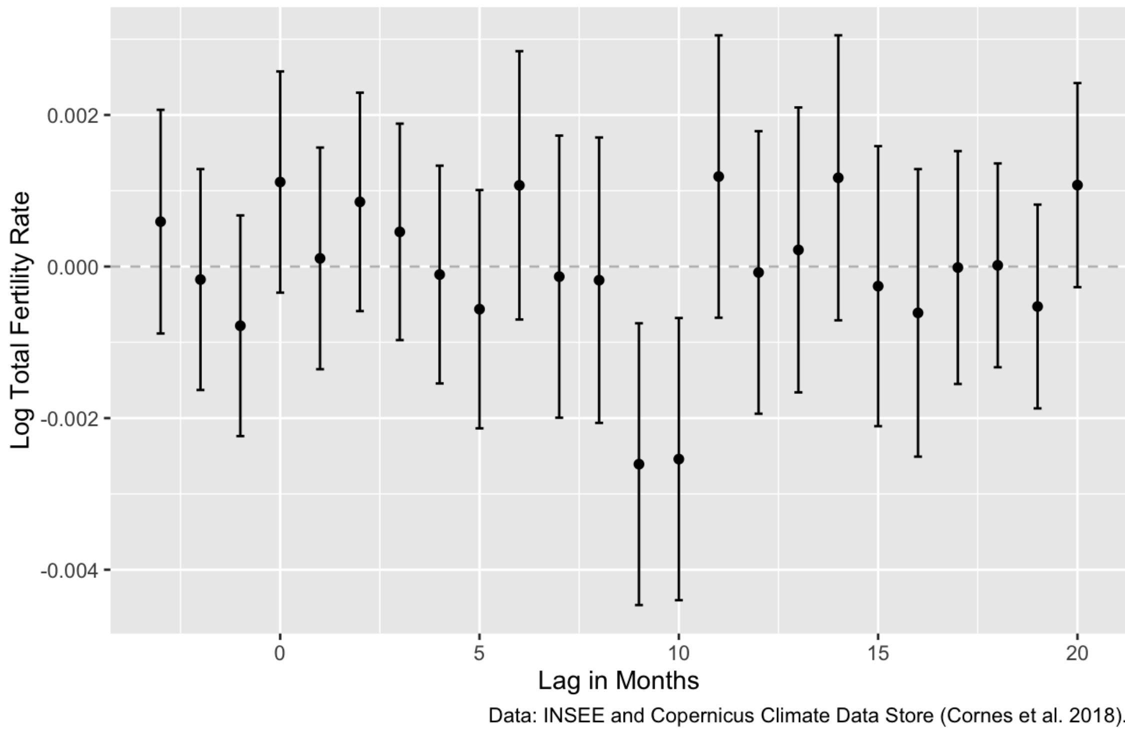

Figure 4.1: Effect of High Temperature on Fertility in 22 French Regions (1975-2020)

Figure 4.1 displays the point estimates (circles) and and +/- 2 standard errors (brackets) of the estimated effect of one day with a mean 24 hour temperature above 25 C relative to a 10-15 C day. I include lagged effects up to 20 months following exposure, as well as placebo checks at -1,-2,-3. I include fixed effects for region by month, year by month, and region by year. I also include linear and quadratic time trends. I control for precipitation and humidity. Standard errors are clustered by region.

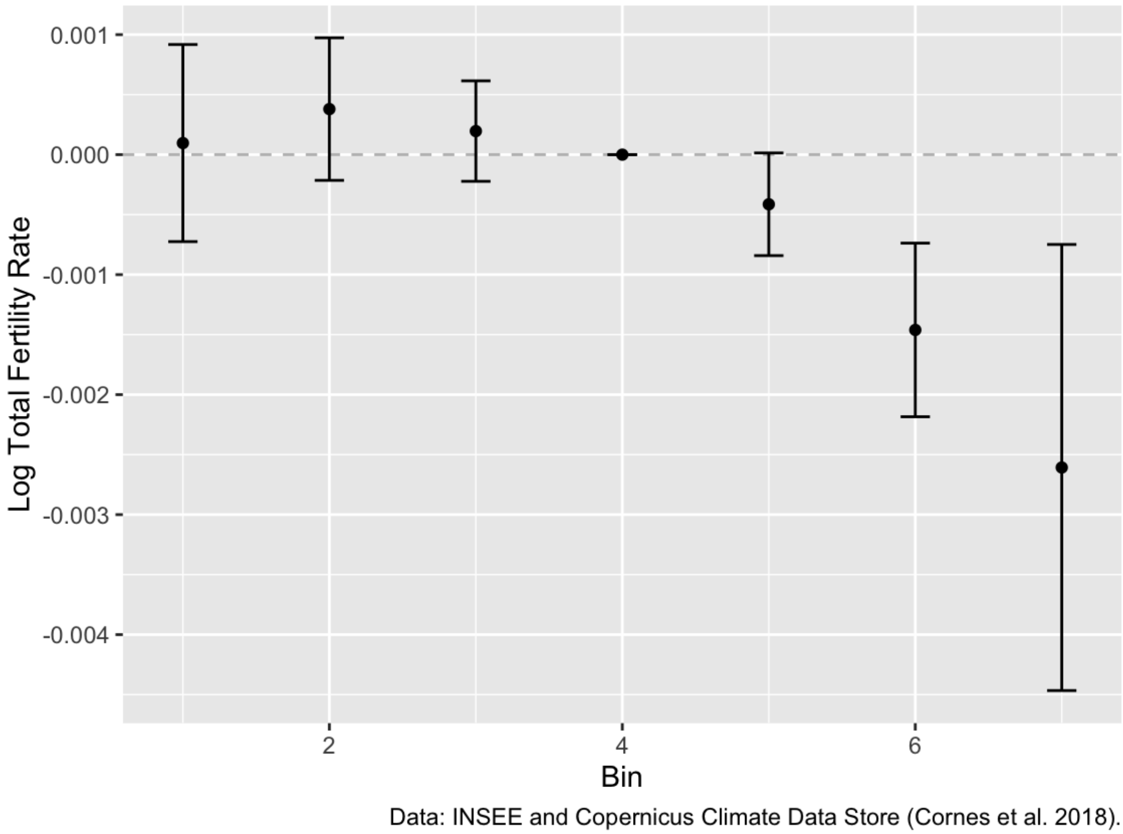

Figure 4.2: Effect Mean Daily Temperature at a Lag on Fertility Rates in 22 French Regions (1975-2020)

Figure 4.2 displays the point estimates (circles) and and +/- 2 standard errors (brackets) of the estimated effect of one day with a mean 24 hour temperature of <0, [0,5), [5,10), [10,15), [15,20), [20, 25), >25 relative to a 10-15 C day, marked bins 1 through 7 respectively. I control lagged effects up to 20 months following exposure, as well as placebo checks at -1,-2,-3, but display only results at a lag of nine months I include fixed effects for region by month, year by month, and region by year. I also include linear and quadratic time trends. I control for precipitation and humidity. Standard errors are clustered by region.

Another finding is that there is no clear catch-up effect in months following the negative shock to fertility rates: that we do not observe a substantial rebound in fertility rates in months afterwards suggests that the effect of fertility on birth rates may result in a permanent loss of births. Figure 4.1 shows that one additional day above 25°C day is associated with a 0.12 percent increase in births 11 months later, though this finding is not statistically significant. As described in section 2.2.1, evidence on French birth seasonality suggests that in the event of unexpected delays in conception, individuals aim to recoup this delay as quickly as possible, as opposed to waiting an entire year for their ideal conception timing to arrive again. In the latter case, women would lose a year of fertility, particularly important as within the wider trend of family postponement under the second demographic transition (Lesthaeghe 2010). Future research may look to harmonize these findings with surveys on completed cohort fertility to assess to what extent this shock creates a tempo effect or a quantum effect.

A final insight from Figure 4.1 is that the placebo checks at -3, -2, -1 months did not yield significant results, providing some assurance regarding the construct validity of the model.

Figure 4.2 focuses on the effects of all the temperature bins at a 9 month lag. Figure 4.2 shows that colder days compared to the reference group do not have a significant effect on birth rates nine months later, which is in line with previous research. Figure 4.2 also displays differences in effect regarding the two highest temperature bins. One additional day in the 20-25°C bin is associated with a 0.15 percent decline in birth rates 9 months later. In contrast, one additional day above 25°C has a larger effect, leading to a 0.26 percent decline in birth rates. Results for all results displayed in Figures 4.1 and 4.2 are available in the Appendix.

In Table 4.2 I compare the core findings of this mémoire as displayed in Figure 4.1 and Figure 4.2 to other studies that use a similar estimation technique on similar quality data in other country contexts. I concentrate on the effect size at a 9 and 10

Authors	Country	Heat Threshold	Lag 9 Months	Lag 10 Months
This Mémoire	France	>25 C	-0.260 %	-0.256 %
Hajdu	Europe	>25 C	-0.68 %	-0.45 %
Hajdu and Hajdu	Hungary	>25 C	-0.18 to -0.85 %	-0.85 to 0 (appr.)
Conte Keivabu et al.	Spain	25-30 C	-0.35 % (appr.)	-0.15 % (appr.)
Barreca et al.	USA	>80 F (26.6 C)	-0.40 %	-0.21 %
Cho	South Korea	>30-32 C	-0.24 %	0.131 % (N/A)

Table 4.2: Estimates at 9 and 10 Month Lag in Proximate Heat/Fertility Literature

month lag, which across country contexts and methodologies has shown the greatest effect size.

Comparing results across studies in this literature is not simple because parameters vary across studies. Estimates are made on a monthly basis with the exception of the analysis of Hungary (T. Hajdu and G. Hajdu 2021) where effect estimates are given by week, up to a lag of 25 weeks (approximately six months) whereas all other studies a span of 20-25 lagged months. Temperature threshold is based on mean daily temperature over a 24-hour period, excluding the analysis of South Korea (Cho 2020) which is based on maximum temperature. I also report coefficients for temperature bins closest to the upper bound of > 25 C I concentrate on here. This is comparable to the work of Hajdu (2024), Hajdu and Hajdu (2022), and Barreca et al. (2018). Due to Spain having a warmer climate, Conte Keivabu et al. (2023) construct an upper bin of > 30 C, which yields an estimated effect of 0.9 % on birth rates. Yet, since I observe hardly any days above 30 C in the French context over the entire period of analysis, I opt to compare their findings from the second highest temperature bin, 25-30 C, which much closer to the level of heat shocks I observe in the case of France.

Results are statistically significant except where noted (N/A). Where results are displayed only graphically, I accompany the result with the note (appr.).

Table 4.2 shows that the effect size observed in France of heat on fertility rates at a nine month lag is on the smaller size of the overall literature, though this is compensated somewhat by the estimate in this analysis remaining similar across lags nine and ten, where other studies see a larger decrease in effect size moving from a lag of nine months to a lag of ten.

While the estimated effect of heat on fertility at a lag of nine months in the French case is smaller than the rest of the literature, that it remains at a similar level to a lag of ten months *and* that we observe no statistically significant catch-up effect as is the case in other studies means the net effect over all lags included here is in line with previous research. Though it is plausible that substantive differences in country context explain the heterogeneity in effect size across different studies, differences in temperature thresholds and reference groups fertility measurement technique between studies mean I cannot go further in hypothesizing *why* different country contexts yield different dynamical results. In the next section, I consider whether this effect has evolved within the period of analysis.

4.3 Results over Time

The window of analysis of this mémoire is long enough to evaluate if the effect of heat on fertility has changed over time. At this point, I may evaluate the second hypothesis of this mémoire: **the effect of heat on fertility will decrease over time (H2).** I observe a decrease in coefficient magnitute from -0.0018 to -0.0008, between the periods of 1975-1997 and 1998-2020, therefore confirming this hypothesis.

This finding is illustrated in Figure 4.3, which illustrates the estimated effect of one day above 20°C compared to a day in the 10-15°C range on log TFR, with temperature lagged 9 months to TFR. Here, I lower the threshold of interest from 25 C to 20 C since the core results indicated the significance of days in bin 6 (daily 24 hour mean temperature of 20-25), alongside days in the top temperature bin (daily 24-hour mean temperature above 25 C). The other model specifications remain

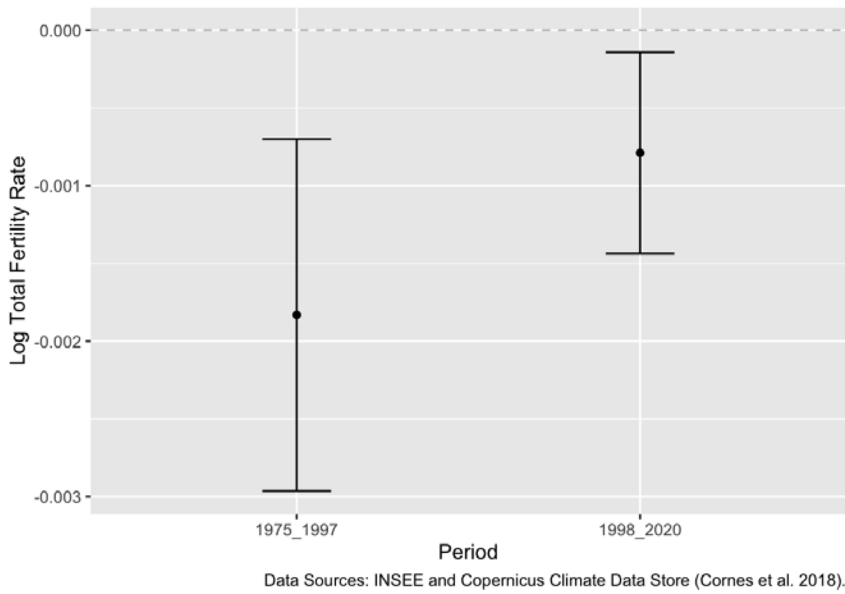

Figure 4.3: The Effect of Heat on Fertility Rates Over Time. 22 Regions, 1975-2020.

Figure 4.3 displays the point estimates (circles) and and +/- 2 standard errors (brackets) of the estimated effect of one day with a mean 24 hour temperature above 20 C relative to a 10-15 C day. I include lagged effects up to 20 months following exposure, as well as placebo checks at -1,-2,-3. I include fixed effects for region by month, year by month, and region by year. I also include linear and quadratic time trends. I control for precipitation and humidity. Standard errors are clustered by region. I apply the estimation technique to two sub-samples of the data, the first including the years 1975-1997, the second including the years 1998-2020

unchanged from that in the core results. It is applied to two sub-samples of the data, one including all observations from the years 1975-1997 and another including all observations from the years 1998-2020 . Each circle denotes the point estimate, and the brackets signify +/- 2 standard deviations.

Regarding how this finding compares to existing literature, in Table 4.2 I list the studies closest in technique to this mémoire and their respective periods of analysis. Of these studies, only Barreca et al. (2018) and Hajdu (2024) have windows of anlaysis large enough to meaningfully decompose their findings temporally. In the

Authors	Country	Window of Analysis
This Mémoire	France	1975-2020
Hajdu	Europe	1969-2020
Hajdu and Hajdu	Hungary	1980-2015
Conte Keivabu et al.	Spain	2010-2018
Barreca et al.	USA	1931-2010
Cho	South Korea	2009-2013

Table 4.3: Periods of Analysis in Proximate Heat/Health Literature

case of the US, Barreca et al. find that the effect of heat on log birth rate diminished from around -0.6 percent in 1950's and 1960's, to around -0.4 pecent in the 1980's to -0.2 percent in the 2000's. This study also provides evidence that widespread air conditioning (AC) adoption in the US during this time explains this change. In contrast, Hajdu finds that in the case of Europe, the effect of heat on fertility rates has remained stable within his window of analysis. That only around 10 percent of EU households have air conditioning compared to around 90 percent of American households may explain this discrepancy (International Energy Agency 2018, pp. 21).

In the case of France, I find that contrary to Hajdu's (2024) finding at the Europe level, there is some decrease in the size of the effect over time. However, this decrease is not as dramatic as observed in the US in terms of relative change. Where in the US Barreca et al. (2018) observe a decrease of two thirds in the coefficient magnitude within their window of analysis, we observe in the case of France a decrease of half, though the effect to begin with was larger in the US in the earlier portion of the analysis of Barreca et al. Also, the analysis of Barreca et al. begins earlier. from the 1980's to the 2000's Barreca et al. find that the effect size diminishes by half, which is closer in time period covered by this mémoire and in result.

One explanation of this dynamic could be because there is less widespread AC adoption in France than in the US. On France, ADEME's 2021 report on air conditioning in France finds a higher penetration rate of 25 percent of households (ADEME 2021, pp. 27), which could explain why France has seen a decrease in heat/fertility effect size where the European effect size has stayed constant. Overall, AC adoption in France has been slower than in the US, and even with recent changes in consumer behavior household adoption rates remain at a fraction of those in the US. Therefore, we would not expect to observe, to exactly the same degree, a technology driven adaptive effect within the heat/fertility relationship in France to the degree observed in the US within the window of this analysis.

It is also possible that other variables are contributing to France's increased resilience to heat/fertility shocks over time. As described in the Heat Wave Governance section, since the severe heat wave of 2003 France has proposed some of the most ambitious heat wave resilience policies within the EU. That these policies were not completely effective at curbing heat wave *mortality* does not mean we can completely rule out any latent positive effect of these heat wave alert systems at promoting resilience or popular awareness that lent resilience to heat wave *fertility* shocks. To elaborate, many heat related deaths both in France and elsewhere are suffered by people who, due to age, illness, or some other reason, are confined to their home (Klinenberg 2002; Keller 2015). On the contrary, that heat may affect the reproductive health of young, otherwise healthy people means that we may expect a higher level of mobility from this population of interest. With the news of a heat wave (as propogated in post-2003 heat wave policy described in section 2.3.2) this population may respond by seeking refuge in a park, an air conditioned space, or leave hot urban areas entirely. The possible role of mobility in lessening the heat/fertility relationship over time may be considered a fruitful area of future research. Also relevant are the labor regulations linked with the heat wave alert system (Ministère du Travail 2023).

4.4 Regional Results

In this section I decompose the national results I have displayed so far to the subnational level. I do this in two ways. First, I divide the regions into two groups, one with historically warmer regions and one containing the historically colder ones, and compare the effect size from these two groups. Dividing the sample into just two groups has the benefit of maintaining a substantial number of observations on which to base these comparative results. The second approach I take is to simplify my core model to render it applicable to one region at a time. This approach produces more spatially granular results, though the simplification of the estimation technique and restriction of number of observations to those coming from just one region lessens the statistical power of the results.

4.4.1 Two Region Groupings

In order to divide the 22 regions at hand into two climactic groupings, I consider the number of days in the top temperature bin (daily 24-hour mean temperature above 25 C) in each region over the entire period of study. I then find the median number of such days across these regions (89 days). I then divide the observations into two groups, one containing the regions that had more than 89 "hot" days within the period of analysis, and the other containing the regions that had less than 89 "hot" days as defined here.

With this grouping, I am able to test the third hypothesis of this mémoire:**colder regions of France are more vulnerable to the effects of heat on fertility than warmer ones (H3).** I find the estimated effect of one day with a mean daily temperature above 20 C relative to a day with a mean temperature between 10 and 15 C at a nine month lag is -0.16 percent in regions with a warmer climate as defined here. I find that under the same conditions, the group of colder regions host an estimated effect of -0.17 percent (Figure 4.4). In short, in the case of France we observe little difference in the estimated effect of days with a mean temperature above 20 C when comparing warmer and colder regions. The key difference in these results, instead, is in the statistical significance of bin 5 (daily mean temperature between 15 and 20 C) in colder regions whereas it is not significant in the warmer regions. This finding suggests that populations in colder regions are susceptible to the effects of heat on fertility at a lower temperature threshold than populations in warmer regions of France, thereby confirming the hypothesis at hand.

Three studies within the closest literature have also embarked on sub-national analysis. Overall, the previous research across country contexts has found fertility rates in historically colder parts of a given country appear to be more sensitive to heat shocks than fertility rates in warmer regions. In the case of the US, Barreca et al. (A. Barreca, Deschenes, and Guldi 2018) find that an additional day above 80 F relative to a 60 - 70 F day yields an effect that is approximately 50 percent larger in colder states than warmer ones. Similarly, Conte Keivabu et al. (Conte Keivabu, Cozzani, and Wilde 2023) find in the case of Spain that an additional day above 30 C relative to a day with a mean temperature between 10-20 has an effect size in colder regions that is approximately three times larger than in warmer regions. Mechanism hypotheses include: a) housing stock in colder climates being optimized for guarding heat rather than optimizing for airflow, and b) populations that are historically less experienced in coping with heat stress will not have developed as resilience as populations in warmer areas.

In contrast Hajdu (T. Hajdu 2024) finds that at the European scale, the difference in effect size between hot and cold countries is smaller than what is previously observed by Barreca et al. (A. Barreca, Deschenes, and Guldi 2018) and Conte Keivabu et al. (Conte Keivabu, Cozzani, and Wilde 2023). Hajdu (T. Hajdu 2024) reports that the effect of one day above 25 C relative to a day at 5-10 C at a 9 month lag yields an effect of -0.68 percent on log birth rates in hot countries, compared to an effect of -0.92 percent on log birth rates in cold countries based on the same conditions. This gives a difference of 0.24 percent.

That the effect of temperature on fertility is visible in the case of France at levels most would consider lower than "extreme" heat is not unprecedented in the literature. Hajdu (2024) reports that at the European level days with a mean temperature

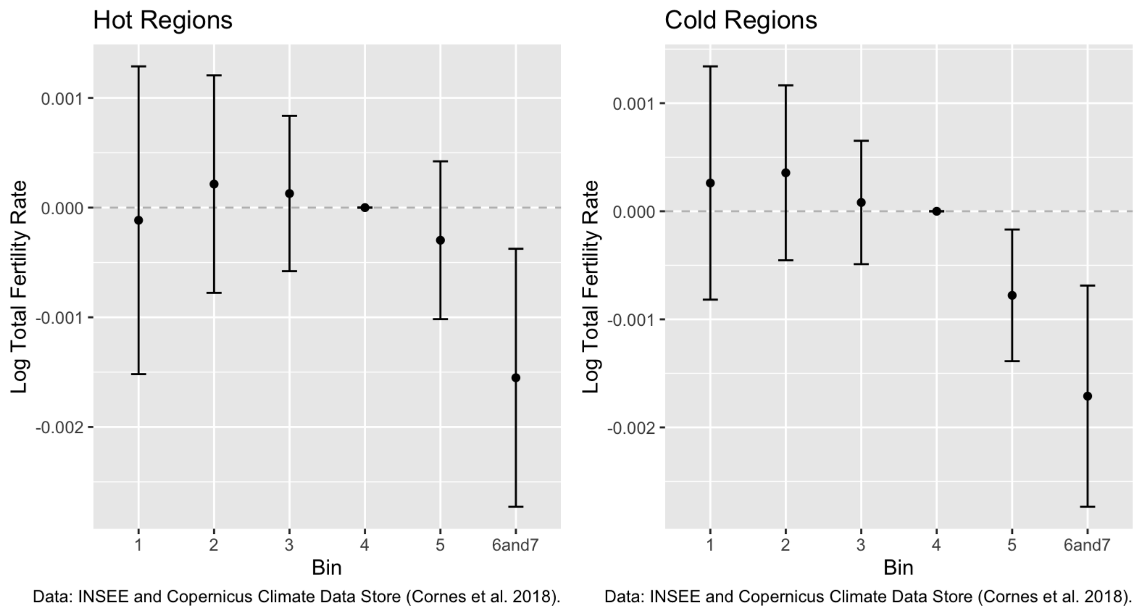

Figure 4.4: Estimated Effect of Temperature on Fertility Rates in Hot and Cold Regions. 22 Regions. 1975-2020

Figure 4.4 displays the point estimates (circles) and and +/- 2 standard errors (brackets) of the estimated effect of one day with a mean 24 hour temperature above 20 C relative to a 10-15 C day. I include lagged effects up to 20 months following exposure, as well as placebo checks at -1,-2,-3. I display graphically the results at lag of 9. I include fixed effects for region by month, year by month, and region by year. I also include linear and quadratic time trends. I control for precipitation and humidity. Standard errors are clustered by region. I apply the estimation technique to two subsamples of the data, based on if regions hosted more or less than the median number of days with a mean temperature over 25 C over the entire window of analysis. Hot Regions: Île-de-France, Centre, Bourgogne, Alsace, Pays de la Loire, Poitou-Charentes, Aquitaine,Midi-Pyrénées , Limousin, Languedoc-Roussillon, Corse. Cold Regions: Champagne-Ardennes, Picardie, Haute-Normandie, Basse-Normandie, Nord-Pas-de-Calais, Lorraine, Franche-Comté, Bretagne, Rhône-Alpes, Auvergne, Provence-Alpes-Cote-d'Azur) between 15 and 20 C have a statistically significant effect of 0.2 percent on birth rates. Though Hajdu (2024) does not report country specific results, we may suspect given the results on France that colder countries in Europe (especially considering those with similar climates to the colder, more northern regions of France such as Belgium, Luxembourg, and Germany) may have a lower temperature threshold after which we may observe the heat/fertility relationship than other country specific literature has suggested so far. This conclusion points to the relevance of considering sub-national, historically relative thresholds as an operationalization of extreme heat, which will be continued in Section 4.7

4.4.2 Regional Level Estimates

In this section I consider regional heterogeneities regarding the effect of heat on fertility at a nine month lag. I use the following fixed effects model specified as:

$$]Y_{rt} = \sum_{j}^{J}\sum_{k}^{K}\beta T^{j}_{r,t-k} + \sum_{k}^{K}\gamma_k P_{r,t-k} + + \sum_{k}^{K}\chi_k H_{r,t-k} + \mu_m + \nu_y + \epsilon_y$$

The independent variable of TFR (Y), and the dependent variables of daily mean temperature (T), precipitation (P) and humidity (H) remain unchanged from the core model described in the previous section. One change I make to these terms is where for temperature I still consider the origional set of bins: <0, [0,5), [5,10), [10,15), [15,20), [20, 25), >25, I display the results considering the effects of one 24 hour day with a mean temperature above 25 C, and given the relevant results at the next temperature bin, I consider the effect of one day above 20 C (practically, this means combining the counts of the top two temperature bins) compared to the same reference group of [10,15).

I restrict analysis to a lag of 9 (k=9) following the findings in the previous section: that the placebo check yields insignificant results, that we do not observe a catch-up in fertility rates in the overall sample, and that the results are most significant at 9 months. Given the limited number of observations per region in this section, I consider only this lag for a better exposition of results. Since I apply this model to each region separately, the fixed effects are simplified. I include a fixed effect for month (μ) and a fixed effect for year (ν). Without the full panel of fixed effects and lags as included in the core results, the coefficients here are (artificially) inflated. As such, the absolute effect sizes estimated in this section must not be considered in isolation. Yet, because we apply the same estimation technique to regions with the same number of observations and the same data quality, the relative differences in coefficients between regions may be of interest, if not the absolute magnitude of the coefficients estimated here. I cluster standard error by year.

Figures 4.4 and 4.5 summarizes the findings from this series of regressions, the complete results of which are available in the Appendix.

I find that fertility rates in the north or France are more affected by heat shocks compared to regions in the south. Regarding the role of housing stock, the findings here track closely with the regional AC adoption figures included in Section 2.3.2. That is to say, there seems to be some correlation between regions with a higher share of houses having AC, and being more resilient to heat shocks. However, housing quality is not the only possible explanation: it may very well be that a wide variety of adaptive measures (such as houses being built with air flow in mind in the first place) and popular awareness of heat (such as resting indoors at the hottest points of the day) plays a role in this regional resilience. Therefore, I cannot conclude if AC adoption is decisive or merely a signal of a wider suite of behaviors.

There are some regions, such as Bretagne and Corse stand as counterpoints that merit more consideration.

The first outlier is Corse, a relatively warm region where the effect appears significant. Based on previous findings in the literature, we would expect a historically warm region to have developed more adaptive capacity against heat waves, as Bar-

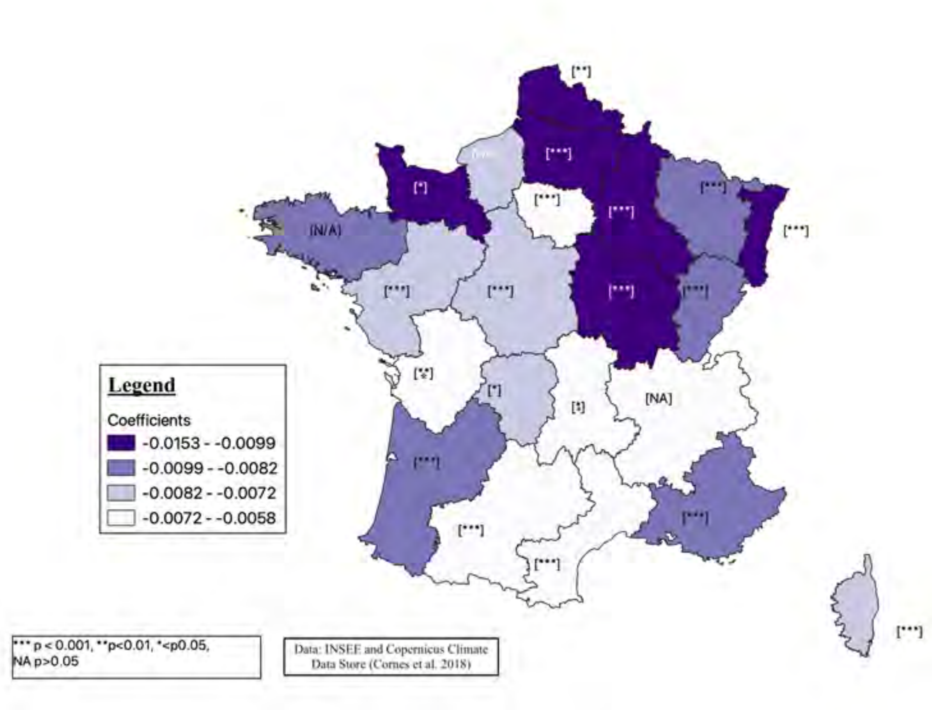

Figure 4.5: Estimated Region Coefficients Effect of One Day Above > 25 C

Figures 4.5 displays the relative difference in estimated effect size between regions of one day with a mean 24 hour temperature above 25 C. relative to a 10-15 C day. I include fixed-effects for month and year and estimate the effect on log TFR at a nine month lag from temperature. I also control for precipitation and humidity.

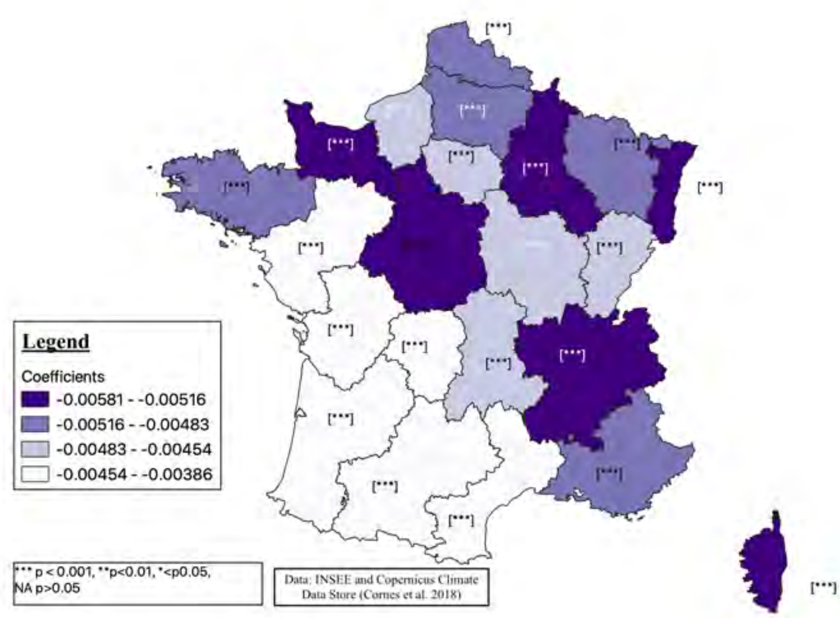

Figure 4.6: Estimated Region Coefficients Effect of One Day Above > 20

Figure 4.6 displays the relative difference in estimated effect size between regions of one day with a mean 24 hour temperature above 20 C. relative to a 10-15 C day. I include fixed-effects for month and year and estimate the effect on log TFR at a nine month lag from temperature. I also control for precipitation and humidity.

reca et al. (2018) demonstrate is the case in the American South. One possible explanation for this contradiction is that even in the warmest regions of France, AC adoption remains low compared to the US. The ADEME reports through their regional groupings of AC adoption that the Mediterranean coast of France and Corse has an AC penetration rate of 47 percent (ADEME 2021, pp. 28). This statistic may not be truly representative of AC adoption strictly in Corse. ADEME includes the Mediterranean coast of France and Corse in the same climate zone- AC penetration data is not available on a more granular level. Yet, this data aggregates some of the richest regions of France such as Provence-Alpes-Côte d'Azur and Occitane (in this analysis, Languedoc Roussillon), with one of the poorest regions of France in Corse. The economic differences between these regions is significant. In 2021, INSEE reports a GDP (PIB) of 180,882 million euros for Provence-Alpes-Côte-d'Azur and a GDP of 182,502 million euros in Occitane. In contrast, Corse reports a 2021 GDP of merely 10,124 million euros (INSEE 2021). In sum, an AC penetration rate of 47 percent in the Mediterranean region of France is still well below the rates proven to have a protective effect in the American south (A. Barreca, Deschenes, and Guldi 2018).

Furthermore, because of the regional differences in economic power within this climatic zone, there may be more granular geographic differences in AC penetration that are invisible with this data. Therefore, a conclusion on the causal effect of AC is not possible here. Other reasonable hypotheses on the outlier status of Corse may include dominant industries on the island, including tourism and agriculture, both of which may contribute to worker heat exposure, particularly in the hottest months of the year. Future research may seek to bridge research that exists on occupational heat exposure and sperm quality on the individual level (e.g (Thonneau et al. 1998)) and how this contributes with the population perspective taken in this mémoire.

The second outlier is Bretagne, a relatively cool region where the effect of heat on fertility is statistically insignificant in Figure 4.5. The lack of statistical significance in the case of Bretagne may be due to a historic lack of heat waves as discussed in section 2.3.1. When we lower the heat benchmark from 25 to 20 C, the magnitude of the coefficient and its significance becomes more aligned with its neighbors. The example of Bretagne demonstrates that a historical lack of heat waves does not insure regions against the effects of heat and fertility for two reasons: 1) The effect is observable at temperature levels lower than what public policy and perhaps public opinion would consider "heat wave level" and 2) as discussed in section 2.3.1, recent years just outside the period of analysis have seen an unprecedented increase in heat wave prevalence in historically temperate regions like Bretagne. Consequently, this data is of limited use in calculating future spatial distribution of risk regarding heat and fertility.

Another outlier region is Île-de-France, where the effect appears to be much smaller than neighboring regions, despite the demonstrated exacerbating effect of the urban heat island on local high temperatures (APUR 2012). It is possible that the internal migration during the vacation period not captured in this analysis is contributing to this unexpected finding, though I am unable to test this hypothesis with the data available here. It is also possible that ambitious urban redesign policies by the Ville de Paris in order to mitigate the heat trapping attributes of an urban built environment have had some effect in mitigating the effects of heat on fertility for those in the region. Whatever the underlying reason, the relatively low effect of heat on fertility rates in Île-de-France is also important due to the region's historical status as the high fertility region within France, as discussed in section 2.2.2.

Perhaps due to these outlier regions, analysis in the French case comparing "hot" and "cold" regions yields results that are not as stark as studies on the US (A. Barreca, Deschenes, and Guldi 2018) and Spain (Conte Keivabu, Cozzani, and Wilde 2023). It may be useful for future research to consider the role of income in mediating the effect of heat on fertility, as the relative wealth of a region appears to be more correlated with a smaller effect of heat on fertility instead of the typical climate of the region. Some explanation related to income or dominant professional occupations within regions could potentially explain why Corse and the northernmost regions of France, as historically less rich areas of France have the same coefficient size emerging from different climates, both in terms of historical climate regimes and recent increase in heat wave events (section 2.3.1). Given the limits of the data here, I am unable to reach a definitive conclusion on the exact mechanisms that support these regional divergences.

In a next step, I consider which regions, within this period of analysis, are most vulnerable to the effects of heat on health from the vantage point of their overall fertility. I consider this by crossing two dynamics: 1) the coefficient size of the heat/fertility relationship estimated earlier in this section, and relative decrease in fertility within the period of analysis for each region. In both Figures 4.7 and 4.8 I concentrate on the estimated coefficients of a day with a mean temperature of 25 C compared to a day of 10-15 C.

In Figure 4.7 I consider that the effects of heat on fertility are more estimated here are more relevant when viewed in light of the most recent period of fertility decline from 2010-2014 to 2020. In essence, the extent to which we may consider the effect of fertility to possibly be a social problem in a given region is if a region is also experiencing greater declines in fertility, which would render the marginal consequence of the heat/fertility effect more consequential than in a region with more stable fertility.

Figure 4.7 illustrates which regions have seen the largest relative fertility decrease within the period of analysis as well as a larger estimated effect of hot days on fertility rates. We observe that Picardie, and other regions in the north of France to host both relatively large declines in fertility and relatively large estimated effect of heat on fertility rates.

I extend this logic to comparing the estimated regional coefficient with the wider climate dynamics. I begin this analysis with the estimated coefficient per region. I then calculate, for each region, the percentage change in the average number of days above 25 C within the periods spanning 1975-2014 compared to the most recent period of 2015-2020. I hypothesise here that the effect of heat on fertility is

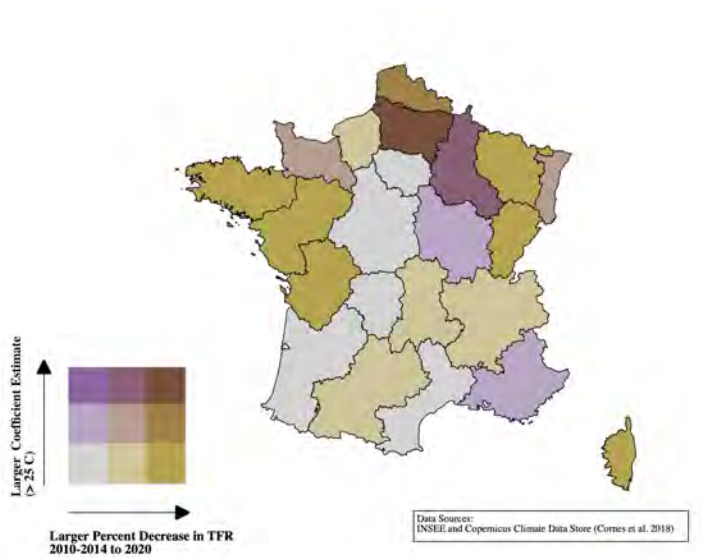

Figure 4.7: Relative Decrease in Fertility and Region Heat/Health Coefficients

Figures 4.7 displays the relative difference in estimated effect size between regions of one day with a mean 24 hour temperature above 25 C. relative to a 10-15 C day. I include fixed-effects for month and year and estimate the effect on log TFR at a nine month lag from temperature. I also control for precipitation and humidity. I compare this result to the percent decrease in TFR from 2010-2014 to 2020

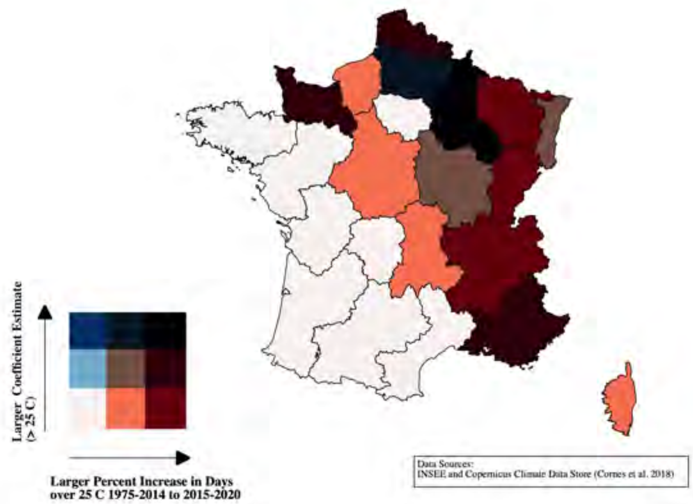

Figure 4.8: Relative Increase in Hot Days and Regional Coefficients

Figures 4.8 displays the relative difference in estimated effect size between regions of one day with a mean 24 hour temperature above 25 C. relative to a 10-15 C day. I include fixed-effects for month and year and estimate the effect on log TFR at a nine month lag from temperature. I also control for precipitation and humidity. I compare this result to the percent increase in hot days, defined here as percentage increase of number of days per year above 25 C from the period of 1975-2015 to 2015-2020

more important from a policy point of view in regions that have recently seen a more substantial increase in hot days compared to regions that have remained relatively temperate. Here, I also reiterate that meteorological data from this window of analysis is not a foolproof indicator of future climate trends, particularly at the regional level where climate modelling increases in uncertainty. This figure must therefore be understood as an illustration of two dynamics strictly within the period of analysis of this mémoire, and not a prescription of future risk.

Figure 4.8 illustrates which regions have the largest percent increase in hot days within the period of analysis as well as a larger estimated effect of hot days on fertility rates. This figure indicates that Champagne-Ardennes, Picardie and Nord-Pas-de-Calais contain relatively large increases in the number of hot days compared to other regions, as well as a relatively large estimated effect of heat on fertility rates. Overall, Figures 4.7 and 4.8 indicate that the regions in Northern France are most vulnerable to the effects of heat on fertility rates for three reasons: the baseline effect is estimated to be larger in these regions, and they host *both* relatively large increases in heat wave days and relatively large decreases in overall fertility rates over the window of analysis. The implications of these findings is that there are meaningful differences in the relationship between heat and fertility at the sub-national level, both in terms of effect size and relative importance in light of wider climate and fertility dynamics.

4.5 Consecutive Hot Days

The heat/fertility literature rarely examines the effects of hot days in a row. Notable exceptions include Barreca et al. (2018) in the case of the US, and Hajdu (2024) in the case of Europe overall. One shortcoming in operationalizing daily temperature into bins that are then aggregated into the monthly level is that it does not take into account the distribution of hot days within a given month. Some months with an equal amount of total hot days may differ in their presentation: in one they may be all in a row due to a heat dome event, or they may be more scattered. However, both months would report the same number hot days in the core model. Yet, we know that instances of hot days in a row are a) increasing in likelihood due to climate change, and that b) they pose a greater risk to human health than one errant hot day. Therefore, this section seeks to test the fourth hypothesis of this mémoire: **the effect of heat on fertility will be larger from hot days within a heat wave event than outside of one (H4).**

For this analysis, I consider how many days in a given month were "heat-wave like" days. I consider three or more hot days in a row as the policy and academic literature has coalesced around at least this portion of a heat wave definition. I consider hot days to be where the mean temperature is either over 20 C in view of statistically significant results at the two highest temperature bins (giving a lower bound of 20 C), seen in the previous section. Here I lower somewhat the threshold used by Méteo-France between a ”canicule” and a ”pic de chaleur”. Then, I apply a condition on all days in bin 6 or 7 in the sample based on if they had at least two days prior also in bin 6 or 7. If so, I considered them as a “heat wave day.” If not, I considered them as a “pic de chaleur”. Another reason I lower the heat wave definition in this section is a concession to the fickle nature of prescribing a binary condition over several consecutive days. In short, I hold that a day just below 25 C that falls between two days above 25 C should not prevent a heat wave classification, since such a discrepancy will still result in very similar health outcomes. Though I concede these specific conditions are arbitrary, the idea is similar to the approach taken by Barreca et al. (A. Barreca, Deschenes, and Guldi 2018) and Hajdu (T. Hajdu 2024) within their supplementary analyses.

Figure 4.9 shows that at a nine month lag, the point estimate of a heat wave day is slightly larger than a non heat wave day, as defined here, regarding their estimated effect on fertility rates (the results are very similar at a ten month lag). Also, the confidence interval is smaller for heat wave days than non heat wave days, signalling less variance in the results, though that these confidence intervals overlap means that further research is needed to make a firm causal claim here, and I cannot confirm H4.

These difference observed here is smaller than has been found in the two previous studies in the proximate literature to investigate this classification. This finding suggests that non-consecutive hot days pose also meaningful risks to reproductive health. Conceptually, this aligns with the findings of the sub-national analysis, which found that in colder regions the effect of heat on fertility emerged at a lower temperature threshold. The common thread in these two results is that the reproductive conse-

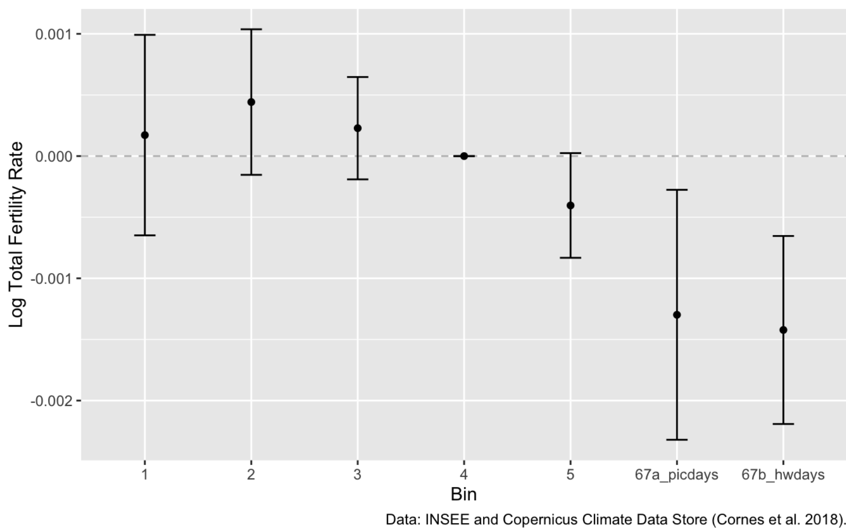

Figure 4.9: Estimated effect of Heat Wave Versus Non Heat Wave Days at a 9 Month Lag on Fertility Rates

Figure 4.9 displays the point estimates (circles) and and +/- 2 standard errors (brackets) of the estimated effect of one day with a mean 24 hour temperature above 20 C relative to a 10-15 C day. I include lagged effects up to 20 months following exposure, as well as placebo checks at -1,-2,-3. I include fixed effects for region by month, year by month, and region by year. I also include linear and quadratic time trends. I control for precipitation and humidity. Standard errors are clustered by region. I distinguish between days above 20 C where the previous two days were also above 20 C (67b-hwdays) and days above 20 C that did not meet this condition (67a-picdays).

quences of heat emerge at lower temperatures and at less days in a row of extreme heat than is required to observe more severe morbidity and mortality due to heat.

4.6 Spline

The previous analysis, and the heat/fertility literature at large, often uses bins to address potential non-linearity of the effect of temperature on fertility at a given lagged month. It is common in both social sciences and proximate fields like epidemiology to divide continuous variables, like income (in this case, temperature) into bins to produce more intuitive results. This method however, is not the only way to deal with nonlinear effects. One fault of considering bins is that a critical point, a specific value in the dependent variable that may have a particularly strong threshold effect on the independent variable, within a bin may be hidden. This is especially true when the intervals are relatively large- I have considered this problem at the moment of my bin construction and for this reason the bins in the previous analysis are among the smallest intervals found in previous literature. Still, it is reasonable to consider other functional approaches as some, but not all, previous studies in this literature have done, for example Barreca et al. (2018) and Hajdu (2024) consider different functional forms in their robustness checks).

Figure 4.10 displays the estimated effect of the monthly average of daily temperature for a given region-month on log TFR nine months later. The estimate is plotted in blue and the shaded areas represent the 95 percent confidence interval. I use a restricted cubic spline with six degrees of freedom, which carries the advantage over natural splines as its behavior is bounded at the extremes of the function. I include fixed effects for region by month, region by year and month by year. I control for precipitation and humidity by including the daily average for a given region-month in the model.[1]

[1]Results in Figures 4.10 and 4.11 are produced and rendered with R packages 'Hmisc' (Harrell

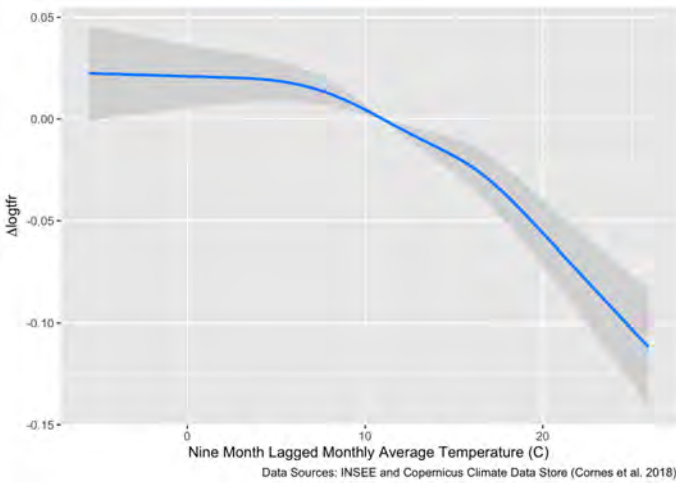

Figure 4.10: Spine of Monthly Mean

Overall, we observe a nonlinear relationship between monthly average temperature and its effect on fertility which matches well with the results already collected via the bins approach. We observe a tipping point in effect size in between 10 and 15 C, which assures the choice of this interval as the reference group made in the case of the core results. Viewing these results also brings out one advantage of the bins approach is it allows us to decompose temperature fluctuations within a given month. Considering a monthly average to accommodate the spline approach obfuscates whether a given month contains several hot days followed by comparatively cool days, or temperate days across the board- this explains why the estimated effect on TFR is smaller here than we observed in the core results. Also, considering the mean monthly temperature across all months somewhat dilutes that the extreme heat shocks are by and large limited to July and August within the sample, which the bins approach also is able to account for.

To investigate these shortcomings, I consider a second spline which considers the average temperature of the five hottest days in a given month. Furthermore, I restrict the analysis to the months of July and August so that the spline results capture any

Jr. and Dupont 2017), and 'Visreg' (Breheny and Burchett 2017)

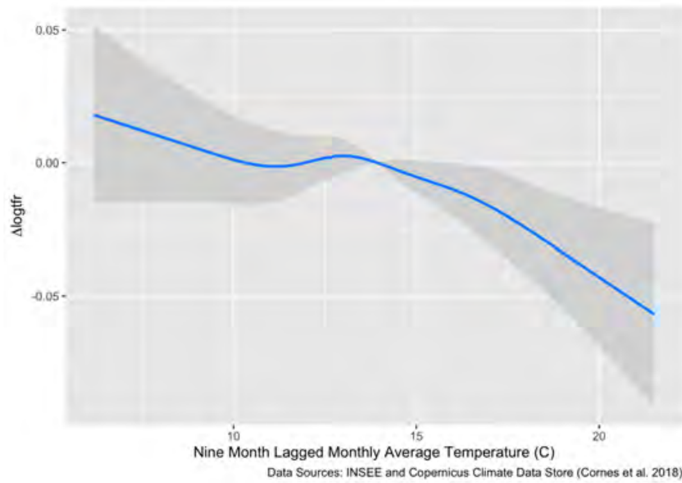

Figure 4.11: Spine of 5 Hottest Days in July and August

temperature threshold that may exist within the hottest periods of the year.

Even with these conditions, we observe a similar behavior to the change over bins in Figure 4.2. With these conditions, we observe a tipping point around 15 C of mean daily temperature. Overall, both of these spline results serve to confirm the fifth hypothesis of this mémoire: **different operational definitions of extreme heat will still yield similar results (H5).**

4.7 Historical Threshold

Though constructing a series of temperature bins is becoming the most common approach in the heat/fertility literature, it is not the only method in the literature for defining extreme heat. In this section, I define heat using a regional historical threshold, as opposed to incremental bins. This serves two purposes. One, it stands as a robustness check for the results garnered in section 4.1: i.e. we gain some assurance that the results so far are not only an artifact of a particular way of defining extreme heat. Two, it allows us to test these two different methods for defining extreme heat under the same data conditions (H5).

One advantage of defining extreme heat according to a historical threshold is that it allows for the same procedure to be exported to analysis of different country contexts. Where researchers have used bins, they necessarily will alter the size and bounds of the bins to account for the climate of the country they are studying. For example, Conte Keivabu et al. (2023)concentrate their analysis on an upper bound bin containing mean daily temperature above 30 C. This is a sensible benchmark for the warm, Mediterranean climate of Spain. Yet, where I consider the neighboring country of France, I cannot take the same upper bound bin. Even during the devastating heat wave of 2003, the *mean* daily temperature in several regions of France remained just below 30 C (maximum temperate notwithstanding). If one were to adopt a top threshold of 30 C in the case of France, there would be vanishingly few days that meet this criteria, meaning that the results would be less reliable. Consequently, the analysis here is not perfectly comparable to this study, despite the potential benefits to garnering perfectly comparable results to a study done on a neighboring country.

Another benefit to using a historical threshold is that it permits us to test the effects of relative heat shocks against absolute ones. As evoked in the regional results and the sociology of heat waves at large, it is not uniquely the absolute temperature shock that dictates health morbidity, but rather the integration between temperature and the adaptive capacity. Therefore, composing a measure of heat based on a relative threshold allows to to observe the effect of heat on fertility even after taking into account the local climate (and, we assume here, popular knowledge and expectations of hot weather).

One study in the heat/fertility literature have used a historical threshold to define anomalous heat events: Marteleto et al. (2023) in the case of Brazil. Marteleto et al. begin by collecting temperature data from a 30-year period prior to the window of analysis of the study. Since the window of analysis of this mémoire begins in 1975, I base my historical threshold on data from 1950 (the earliest data available from the Copernicus Climate Data Store) to 1974 (the year before my window of analysis begins). Next, Marteleto et al. consider dummies that indicate extreme heat events, where the average temperature in a given month is outside the historical average, plus or minus two standard deviations.

Because the seasonal climate of Brazil varies more by precipitation than temperature, I modify this measure for the French context. First, I apply the procedure only to the months of June, July, and August, which are the months in the window of analysis in which heat waves occur. Considering a positive temperature anomaly outside these months might falsely flag a mild winter as an extreme heat event. Next, I only the threshold as plus two standard deviations from the historical threshold. In sum, any region-month within the period of analysis to have a mean daily temperature two standard deviations above the historical average is assigned an indicator value of 1. Any region-months that do not meet this criteria are marked zero.

I find that under this operationalization, we still observe a negative effect of temperatures on fertility rates around nine and ten months, providing support to H5. However, the point estimates across the lags estimated are skewed negatively compared to the core results, where they lie closer to zero. It is possible that using a binary variable here may be resulting in false negatives- months just below the threshold that trigger similar health effects. At the same time, the point estimates for the lags of interest are found to be smaller here than in the core results. Statistically significant negative results at lags that have no prior explanation in the literature, such as 16, 19, may lead us to suspect these discrepancies are an artifact of the estimation technique instead of a substantive difference in findings. Despite some theoretical advantages to considering a historical deviation instead of a uniform threshold across all regions, the results obtained here are still less clear than those obtained with the bin approach.

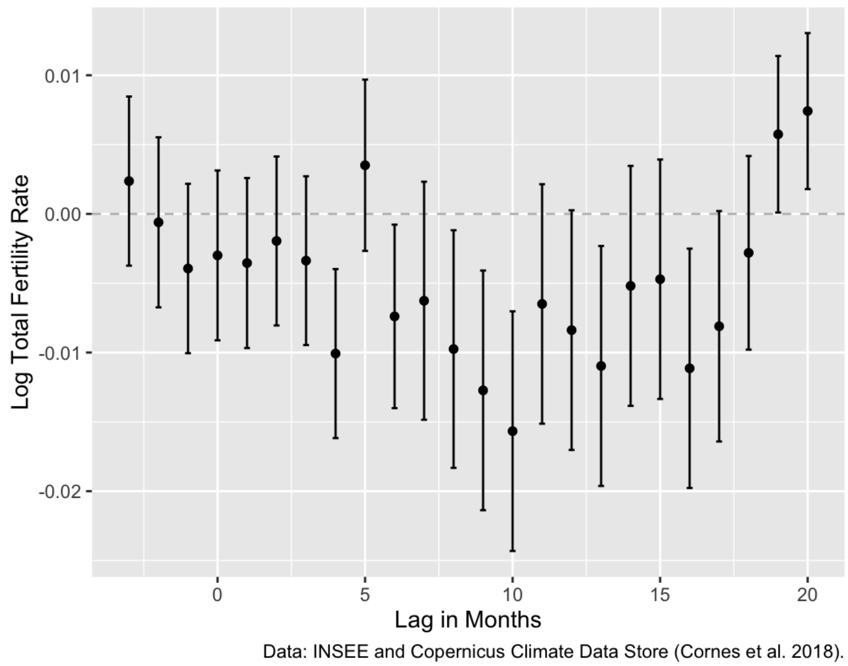

Figure 4.12: Historical Threshold

Figure 4.12 displays the point estimates (circles) and and +/- 2 standard errors (brackets) of the estimated effect of a month (June, July or August) 2 standard deviations above the historical average from 1950-1974 for each month. I include lagged effects up to 20 months following exposure, as well as placebo checks at -1,-2,-3. I include fixed effects for region by month, year by month, and region by year. I also include linear and quadratic time trends. I control for precipitation and humidity. Standard errors are clustered by region.

Chapter 5

Conclusion and Discussion

5.1 Conclusion

This study finds that the relationship between heat and fertility observed in other countries can also be observed in France. I find that this relationship may be linked to extreme heat nine and ten months prior to the month of birth, confirming the first hypothesis of this analysis: **Heat waves have a negative effect on fertility rates in France (H1).** Previous research on this subject with more temporally granular data has connected this lag to the mechanism of disrupted spermatogenesis (A. Barreca, Deschenes, and Guldi 2018; T. Hajdu and G. Hajdu 2022). Given the limitations of the data here, I cannot firmly conclude if in the French case, it is disrupted spermatogenesis or changes in sexual behavior that explain this finding. However, since the relationship is visible over two months, I consider that spermatogenesis is the more likely explanation.

I also find that the estimated effect has decreased in amplitude over time, confirming the second hypothesis of this analysis: **The effect of heat on fertility will de-**

crease over time (H2). Possible reasons for this change include changes in public policy and increased AC adoption. However, I cannot ascertain the portion of the change owed to each explanation, or if another unobserved long-term trend has also contributed, such as changes in summer mobility patterns.

I also find that effect of heat on fertility differs by region. Cooler regions experience a lower temperature threshold at which the connection between heat and fertility becomes statistically significant, which confirms the third hypothesis of this mémoire: **colder regions of France are more vulnerable to the effects of heat on fertility than warmer ones (H3).**

I analyze the role of consecutive hot days and find that they have a slightly larger point estimate and less variance in effect size than non heat wave days. Yet, these differences are not large enough to confirm the fourth hypothesis of this work: **the effect of heat on fertility will be larger from hot days within a heat wave event than outside of one (H4).**

I also explore my core findings by different methodological perspectives. These include the use of a different functional form and defining extreme heat through a relative, not absolute threshold. The core findings remain relevant across these changes, confirming the final hypothesis of this work: **Different operational definitions of extreme heat will still yield similar results (H5).**

These findings must be viewed in light of several limitations of this research. First, the temporal granularity of this study is limited by fertility data being available by month, and not by week. Previous work in this research stream that relies on weekly fertility data is able to go further than this study in discussing possible mechanisms that lead to decreased conception probabilities. Second, the regional level of the fertility data constrains the spatial granularity of the study. Meteorological variables, even on a given day, may vary with regions and taking a simple mean overlooks this heterogeneity.

Furthermore, I do not weigh the meteorological variables in accordance with heterogeneities in population at the sub regional level. Therefore, temperatures experienced by urban populations, as a larger proportion of the region as a whole, are underrepresented. The urban heat island effect further complicates measuring extreme heat experienced by urban populations. Weather stations included in the EU Copernicus database used here are commonly located in parks or airports outside the city center, which may be several degrees cooler than temperatures in the city center (cf. regarding the Paris case: (APUR 2012)).

I also do not account for migration between regions between the timing of conception and of birth. This is especially relevant in this case since heat waves often come during the period of *vacances* in France, a period of exceptional internal migration. Furthermore, I am not able to measure directly the role of socioeconomic status at the individual level in mediating the connection between heat and fertility. Individuals of higher socioeconomic status may be more likely to take vacations outside hot city centers. One could also hypothesize on the role of indoor versus outdoor labor in subtracting or adding daily heat exposure heterogeneously according to socioeconomic status at the sub-regional level.

While I am not able to directly measure the role of socioeconomic status at the individual level in mediating the connection between heat and fertility, I have nevertheless sought to include a socioeconomic perspective where possible, specifically as seen through housing quality at the regional level. Future sociological research could certainly improve upon this analysis with more granular data, eventually building an framework considering inequalities in heat and fertility risk that approaches the detail and scope that has been accomplished for inequalities in heat and mortality risk. This is particularly relevant with regards to the roles of socieconomic status, occupational status and mobility.

Another conceivable improvement to the work done here is to include a comprehensive analysis of the role of air quality with the relationship between heat and fertility.

Medical research on the topic has suggested that poor air quality has a negative effect on sperm quality. In a heat dome event, poor air quality and extreme heat often coincide, since the heat dome traps particles that would normally be cleared out by wind or precipitation. Future research could control for, and also investigate the role of, air quality using detailed global air quality data compiled by the Atmospheric Composition Analysis group at Washington University in St. Louis (Van Donkelaar et al. 2021). Conte Keivabu et al. (Conte Keivabu, Cozzani, and Wilde 2023) have set an example by including such variables in their heat/fertility analysis of Spain.

Turning to methodology, the heat-fertility literature and the New Climate-Economy Literature in general has coalesced around the operationalization of temperature as a series of categorical variables (bins), in tandem with a series of fixed-effects. I demonstrate in this mémoire that there are several advantages of this approach compared to the others tested with the same underlying data, such as the ability to decompose daily temperatures within a month, the ability to see to some extent nonlinear effects, and ease of interpretation of coefficients.

That this approach is coming to be the "normal science" of heat/fertility research does not mean that no improvements to the estimation technique can be imagined. Fixed-effects models remain an imperfect method for establishing causal links, as the results are not tested on a counterfactual (i.e. would we observe the same fertility shock in region x at year y if the heat wave had never occurred? Future years having already exposed to a treatment do not represent an absolutely perfect counterfactual). Furthermore, splitting temperature into bins assumes perfectly linear behavior within each bin. I problematize this in my results section using a spline, but one could go further and consider a Gaussian process model, which would not require setting knots as in the case of a spline (Gelman et al. 1995, Chapter 21).

One strength of this mémoire is that it is based on a TFR calculation technique and meteorological database that is exportable to other country contexts, especially within Europe as the Copernicus database offers comprehensive data across much of the continent. Therefore, another pathway of future research could be to expand the geographic scope of this research to include a regional analysis of neighboring countries using the same data and estimation technique. Studying similar climactic zones that fall on different sides of national borders could better generate hypotheses on the role of national policies in mediating the heat/fertility relationship. Though my choice of methodology and discussion of results have aimed to place the results here in conversation with work done on different country contexts, it does not replace the insights that a unified, multi-country comparative analysis could eventually offer.

More broadly, this work could also benefit from complementary qualitative methodologies. Studying population level fertility rates, even on a more temporally granular weekly basis, approaches only asymptotically a description of mechanisms that cause this heat/fertility relationship. This literature, so far, has only hypothesized at the comparative prevalence of a suite of posssible individual health mechanisms. Neyer (Neyer et al. 2013) notes that demography as a whole stands to benefit from more methodological diversity, as population level data has limited power to reveal individual decision making pathways.

5.2 Discussion

These specific findings, coupled with their alignment with the wider literature on the relationship between heat and fertility carries several larger implications. I began this mémoire with a discussion on how the work of Catton and Dunlap (1978) expanded the perspective of sociology concerning its objects of study. They argued convincingly that putting meteorological and social variables in dialogue would serve to enrich sociological inquiry. This mémoire demonstrates the merits of such a methodological perspective in generating avenues for future sociological inquiry on the problem of climate change.

While policymakers and previous sociological literature have understandably focused on the effects of heat waves on mortality, this mémoire shows is that to regard heat waves as uniquely a problem of mortality is to overlook its effect on another demographic dynamic- fertility. This mémoire shows this relationship to be present in yet another country context and robust across several estimation techniques. This finding may challenge preconceived notions of who is "at risk" from the effects of heat. The negative effect of fertility I document here pertains to young adults that may otherwise be in good health- a population which is not commonly thought of to be of concern during heat events.

These findings also challenge popular notions of what levels of heat may trigger adverse health effects. I find that days with a mean temperature between 15-20 C are enough to observe a statistically significant effect of heat on fertility in cold regions, where populations and built environments are less adapted to hot weather that is evolving to be ubiquitous across climactic zones. A key lesson from this analysis is that *all* populations stand some type and degree of risk from heat waves and therefore climate change at large. This is especially true in regions are not historically accustomed to heat as a hazard. Eventual policies that seek to address the link between heat and fertility must consider this sub-national heterogeneity.

Another key implication of this mémoire's findings is how difficult it is to foresee how climate change will affect future fertility rates. The estimation technique I employ relies on estimating the effect of one additional day of hot weather. When viewed in the wider perspective of a rapidly changing climate regime where hot days are increasing in number and severity, this does not perfectly capture how complex future effects of heat on fertility may become.

Throwing even more uncertainty into the future stakes of this research is that our planetary system is subject to change on the basis of imperfectly known tipping points, not linear trends. In coming decades climate hazards may occur at a pace and severity that could strain current adaptive infrastructures, challenging many of the findings of this mémoire. Adding uncertainty still, the years following the window of analysis of this mémoire, fertility rates have continued to decline in France at a pace that defies perfect explanation. The findings of this mémoire affirm that climate change's role within wider fertility decline deserves continued attention.

Bibliography

ADEME (2021). *La climatisation de confort dans les bâtiments résidentiels et tertiaires*. ADEME, CODA Strategies, p. 110. URL: https://librairie.ademe.fr/changement-climatique-et-energie/4745-la-climatisation-de-confort-dans-les-batiments-residentiels-et-tertiaires.html?search_query=climatisation&results=46.

APUR (2012). *Les Îlots de Chaleur Urbains à Paris*. Atelier Parisien d'Ubanisme (APUR). URL: https://www.apur.org/sites/default/files/documents/publication/documents-associes/ilot_chaleur_urbains_paris_cahier1.pdf?token=HAr5ynNS.

Barreca, Alan, Olivier Deschenes, and Melanie Guldi (2018). "Maybe Next Month? Temperature Shocks and Dynamic Adjustments in Birth Rates". In: *Demography* 55.4, pp. 1269–1293. ISSN: 1533-7790. DOI: 10.1007/s13524-018-0690-7. URL: https://doi.org/10.1007/s13524-018-0690-7.

Barreca, Alan I. (Jan. 1, 2012). "Climate change, humidity, and mortality in the United States". In: *Journal of Environmental Economics and Management* 63.1, pp. 19–34. ISSN: 0095-0696. DOI: 10.1016/j.jeem.2011.07.004. URL: https://www.sciencedirect.com/science/article/pii/S0095069611001033.

Basu, Rupa et al. (Nov. 1, 2018). "Temperature and Term Low Birth Weight in California". In: *American Journal of Epidemiology* 187.11, pp. 2306–2314. ISSN: 0002-9262. DOI: 10.1093/aje/kwy116. URL: https://doi.org/10.1093/aje/kwy116 (visited on 02/21/2023).

Beck, Ulrich (1992). *Risk society: towards a new modernity.* Theory, culture & society. London ; Newbury Park, Calif: Sage Publications. 260 pp. ISBN: 978-0-8039-8345-8 978-0-8039-8346-5.

Becker, Gary S. (1991). *A treatise on the family.* Enl. ed. Cambridge, Mass: Harvard University Press. 424 pp. ISBN: 978-0-674-90698-3.

Benatar, David (2008). *Better never to have been: the harm of coming into existence.* Oxford: Clarendon press. ISBN: 978-0-19-954926-9.

Boni, Zofia et al. (Sept. 2023). "What is a heat(wave)? An interdisciplinary perspective". In: *Climatic Change* 176.9, p. 129. ISSN: 0165-0009, 1573-1480. DOI: 10.1007/s10584-023-03592-3. URL: https://link.springer.com/10.1007/s10584-023-03592-3 (visited on 02/21/2024).

Boyle, Paul (Oct. 1, 2003). "Population geography: does geography matter in fertility research?" In: *Progress in Human Geography* 27.5. Publisher: SAGE Publications Ltd, pp. 615–626. ISSN: 0309-1325. DOI: 10.1191/0309132503ph452pr. URL: https://doi.org/10.1191/0309132503ph452pr (visited on 02/29/2024).

Breheny, Patrick and Woodrow Burchett (2017). "Visualization of Regression Models Using visreg". In: *The R Journal* 9.2, pp. 56–71.

Buelens, Mathieu (Mar. 1, 2022). "Recent changes in the spatial organisation of European fertility: Examining convergence at the subnational and transnational level (1960-2015)". In: *Espace populations sociétés. Space populations societies* 2022. Number: 2022/1 Publisher: Université des Sciences et Technologies de Lille. ISSN: 0755-7809. DOI: 10.4000/eps.12255. URL: https://journals.openedition.org/eps/12255 (visited on 02/29/2024).

Candau, Jacqueline and Valérie Deldreve (2015). "Environmental Sociology in France (1984-2014)". In: *Revue d'Études en Agriculture et Environnement*, pp. 17–41. ISSN: 1966-9607. URL: https://www.persee.fr/doc/reae_1966-9607_2015_num_96_1_2182.

Caplan, Patricia, ed. (2000). *Risk revisited.* 1. publ. Anthropology, culture, and society. London: Pluto Press. 258 pp. ISBN: 978-0-7453-1463-1 978-0-7453-1468-6.

Catton, William R. and Riley E. Dunlap (1978). "Environmental Sociology: A New Paradigm". In: *The American Sociologist* 13.1. Publisher: Springer, pp. 41–49.

ISSN: 00031232, 19364784. URL: http://www.jstor.org/stable/27702311 (visited on 10/04/2023).

Cho, Hyunkuk (2020). "Ambient temperature, birth rate, and birth outcomes: evidence from South Korea". In: *Popul Environ* 41.3, pp. 330–346. ISSN: 0199-0039. DOI: 10.1007/s11111-019-00333-6.

Conte Keivabu, Risto and Marco Cozzani (2022). "Extreme Heat, Birth Outcomes, and Socioeconomic Heterogeneity". In: *Demography* 59.5, pp. 1631–1654. ISSN: 1533-7790. DOI: 10.1215/00703370-10174836.

Conte Keivabu, Risto, Marco Cozzani, and Joshua Wilde (2023). *Temperature and fertility: evidence from Spanish register data*. WP-2023-021. Edition: 0. Rostock: Max Planck Institute for Demographic Research, WP–2023–021. DOI: 10.4054/MPIDR-WP-2023-021. URL: https://www.demogr.mpg.de/en/publications_databases_6118/publications_1904/mpidr_working_papers/temperature_and_fertility_evidence_from_spanish_register_data_7755 (visited on 12/09/2023).

Cordier, Solene (Jan. 17, 2024). "Emmanuel Macron annonce un congé de naissance et un plan contre l'infertilité en vue du réarmement démographique du pays". In: *Le Monde*. URL: https://www.lemonde.fr/societe/article/2024/01/17/emmanuel-macron-annonce-un-conge-de-naissance-et-un-plan-contre-l-infertilite-pour-le-rearmement-demographique-du-pays_6211291_3224.html.

Cornes, Richard C. et al. (2018). "An Ensemble Version of the E-OBS Temperature and Precipitation Data Sets". In: *JGR Atmospheres* 123.17, pp. 9391–9409. ISSN: 2169-897X, 2169-8996. DOI: 10.1029/2017JD028200. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017JD028200 (visited on 04/24/2024).

Croissant, Yves and Giovanni Millo (2008). "Panel Data Econometrics in R: The plm Package". In: *Journal of Statistical Software* 27.2, pp. 1–43. DOI: 10.18637/jss.v027.i02.

– (2018). *Panel Data Econometrics with R*. Wiley.

DeGrazia, David (Aug. 2010). "Is it wrong to impose the harms of human life? A reply to Benatar". In: *Theor Med Bioeth* 31.4, pp. 317–331. ISSN: 1386-7415, 1573-

1200. DOI: 10.1007/s11017-010-9152-y. URL: http://link.springer.com/10.1007/s11017-010-9152-y (visited on 03/26/2024).

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken (Sept. 1, 2014). "What Do We Learn from the Weather? The New Climate-Economy Literature". In: *Journal of Economic Literature* 52.3, pp. 740–798. ISSN: 0022-0515. DOI: 10.1257/jel.52.3.740. URL: https://pubs.aeaweb.org/doi/10.1257/jel.52.3.740 (visited on 02/22/2024).

Desplanques, Guy (Dec. 31, 2011). "Les disparités géographiques de fécondité en France". In: *Espace populations sociétés. Space populations societies* 2011. Number: 2011/3 Publisher: Université des Sciences et Technologies de Lille, pp. 459–473. ISSN: 0755-7809. DOI: 10.4000/eps.5258. URL: https://journals.openedition.org/eps/5258 (visited on 02/29/2024).

Dillarstone, Hope, Laura J. Brown, and Elaine C. Flores (Nov. 9, 2023). "Climate change, mental health, and reproductive decision-making: A systematic review". In: *PLOS Clim* 2.11. Ed. by Fanli Jia, e0000236. ISSN: 2767-3200. DOI: 10.1371/journal.pclm.0000236. URL: https://dx.plos.org/10.1371/journal.pclm.0000236 (visited on 02/21/2024).

Dunlap, Riley E., ed. (2002). *Sociological theory and the environment: classical foundations, contemporary insights*. Lanham, Md.: Rowman & Littlefield. 357 pp. ISBN: 978-0-7425-0186-7 978-0-7425-0185-0.

Dunlap, Riley E. and Robert J. Brulle, eds. (2015). *Climate change and society: sociological perspectives*. New York, NY: Oxford University Press. 460 pp. ISBN: 978-0-19-935610-2 978-0-19-935611-9.

Dunlap, Riley E. and William Michelson, eds. (2002). *Handbook of environmental sociology*. Westport, Conn. London: Greenwood Press. 602 pp. ISBN: 978-0-313-26808-3.

Dupâquier, Jacques (1976). "Les caractères originaux de l'histoire démographique française au XVIIIe siècle". In: *Revue d'Histoire Moderne & Contemporaine* 23.2. Company: Persée - Portail des revues scientifiques en SHS Distributor: Persée - Portail des revues scientifiques en SHS Institution: Persée - Portail des revues scientifiques en SHS Label: Persée - Portail des revues scientifiques en SHS Publisher:

Société d'histoire moderne et contemporaine, pp. 182–202. DOI: 10.3406/rhmc.1976.2357. URL: https://www.persee.fr/doc/rhmc_0048-8003_1976_num_23_2_2357 (visited on 02/22/2024).

Gelman, Andrew et al. (June 1, 1995). *Bayesian Data Analysis*. 0th ed. Chapman and Hall/CRC. ISBN: 978-1-135-43941-5. DOI: 10.1201/9780429258411. URL: https://www.taylorfrancis.com/books/9781135439415 (visited on 04/25/2024).

Geruso, Michael, Melissa LoPalo, and Dean Spears (Sept. 2021). "Temperature, Humidity, and Human Fertility: Evidence from 58 Developing Countries". In: *Population Wellbeing Initiative at the UT-Austin PRC*. White Paper No. 4.

Giddens, Anthony (1997). *The consequences of modernity*. 6th pr. Stanford, Calif: Stanford Univ. Press. 186 pp. ISBN: 978-0-8047-1891-2 978-0-8047-1762-5.

Grace, Kathryn (July 2017). "Considering climate in studies of fertility and reproductive health in poor countries". In: *Nature Clim Change* 7.7, pp. 479–485. ISSN: 1758-678X, 1758-6798. DOI: 10.1038/nclimate3318. URL: https://www.nature.com/articles/nclimate3318 (visited on 04/17/2024).

Gray, Clark and Brian C. Thiede (Mar. 12, 2024). "Temperature anomalies undermine the health of reproductive-age women in low- and middle-income countries". In: *Proc. Natl. Acad. Sci. U.S.A.* 121.11, e2311567121. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.2311567121. URL: https://pnas.org/doi/10.1073/pnas.2311567121 (visited on 04/17/2024).

Gschrey, Barbara et al. (June 1, 2011). "High increase of global F-gas emissions until 2050". In: *Greenhouse Gas Measurement and Management* 1.2. Publisher: Taylor & Francis, pp. 85–92. ISSN: 2043-0779. DOI: 10.1080/20430779.2011.579352. URL: https://doi.org/10.1080/20430779.2011.579352.

Hajdu, Tamás (2024). "The effect of temperature on birth rates in Europe". In: *Popul Environ* 46.1, p. 9. ISSN: 0199-0039, 1573-7810. DOI: 10.1007/s11111-024-00450-x. URL: https://link.springer.com/10.1007/s11111-024-00450-x (visited on 04/17/2024).

Hajdu, Tamás and Gábor Hajdu (2019). "Ambient temperature and sexual activity: Evidence from time use surveys". In: *DemRes* 40, pp. 307–318. ISSN: 1435-9871.

DOI: 10.4054/DemRes.2019.40.12. URL: https://www.demographic-research.org/volumes/vol40/12/ (visited on 05/06/2024).

Hajdu, Tamás and Gábor Hajdu (2021). "Temperature, climate change, and birth weight: evidence from Hungary". In: *Popul Environ* 43.2, pp. 131–148. ISSN: 1573-7810. DOI: 10.1007/s11111-021-00380-y. URL: https://doi.org/10.1007/s11111-021-00380-y (visited on 02/21/2023).

– (2022). "Temperature, climate change, and human conception rates: evidence from Hungary". In: *J Popul Econ* 35.4, pp. 1751–1776. ISSN: 0933-1433, 1432-1475. DOI: 10.1007/s00148-020-00814-1. URL: https://link.springer.com/10.1007/s00148-020-00814-1 (visited on 04/17/2024).

– (2023). "Climate change and the mortality of the unborn". In: *Journal of Environmental Economics and Management* 118, p. 102771. ISSN: 0095-0696. DOI: 10.1016/j.jeem.2022.102771. URL: https://www.sciencedirect.com/science/article/pii/S0095069622001243 (visited on 12/12/2023).

Harrell Jr., F. and C. Dupont (2017). *Hmisc: Harrell miscellaneous*. Washington, D.C. URL: https://CRAN.R-project.org/package=Hmisc.

He, Cheng et al. (Aug. 2022). "The effects of night-time warming on mortality burden under future climate change scenarios: a modelling study". In: *The Lancet Planetary Health* 6.8, e648–e657. ISSN: 25425196. DOI: 10.1016/S2542-5196(22)00139-5. URL: https://linkinghub.elsevier.com/retrieve/pii/S2542519622001395 (visited on 02/22/2024).

Holleman, Hannah (2020). "Classical Theory and Environmental Sociology: Toward Deeper and Stronger Roots". In: *The Cambridge Handbook of Environmental Sociology*. Ed. by Michael M. Bell et al. Vol. 1. Cambridge: Cambridge University Press, pp. 11–29. ISBN: 978-1-108-42932-0. DOI: 10.1017/9781108554510.003. URL: https://www.cambridge.org/core/product/FE3735CE3A99D2D80EF9C81EF91031EF.

Houdaille, Jacques (Mar. 1985). "Le mouvement saisonnier des naissances dans la France rurale de 1640 à 1669". In: *Population (French Edition)* 40.2, p. 360. ISSN: 00324663. DOI: 10.2307/1533143. URL: https://www.jstor.org/stable/1533143?origin=crossref (visited on 02/22/2024).

Hunter, Lori M. and Daniel H. Simon (2021). "Environmental Demography". In: *Handbook of Environmental Sociology*. Ed. by Beth Schaefer Caniglia et al. Series Title: Handbooks of Sociology and Social Research. Cham: Springer International Publishing, pp. 405–423. ISBN: 978-3-030-77711-1 978-3-030-77712-8. DOI: 10.1007/978-3-030-77712-8_19. URL: https://link.springer.com/10.1007/978-3-030-77712-8_19 (visited on 04/17/2024).

INSEE (Apr. 29, 2021). *La France et ses territoires*. Institut National de la Statistique et des Études Économiques. URL: https://www.insee.fr/fr/statistiques/5039923?sommaire=5040030.

– (Feb. 29, 2024a). *L'essentiel sur… l'Île-de-France*. URL: https://www.insee.fr/fr/statistiques/4481962.

– (Feb. 29, 2024b). *Les naissances par mois en 2021, 2022, 2023 et 2024*. INSEE. URL: https://www.insee.fr/fr/statistiques/7929493?sommaire=5348638.

Intergovernmental Panel On Climate Change (July 6, 2023). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 1st ed. Cambridge University Press. ISBN: 978-1-00-915789-6. DOI: 10.1017/9781009157896. URL: https://www.cambridge.org/core/product/identifier/9781009157896/type/book (visited on 04/16/2024).

International Energy Agency (2018). *The Future of Cooling*. International Energy Agency, p. 92. URL: https://www.iea.org/reports/the-future-of-cooling.

IPCC (June 9, 2022). *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. 1st ed. Cambridge University Press. ISBN: 978-1-00-915794-0 978-1-00-915795-7. DOI: 10.1017/9781009157940. URL: https://www.cambridge.org/core/product/identifier/9781009157940/type/book (visited on 04/23/2024).

Jiménez-Esteve, B., K. Kornhuber, and D. I. V. Domeisen (Nov. 16, 2022). "Heat Extremes Driven by Amplification of Phase-Locked Circumglobal Waves Forced by Topography in an Idealized Atmospheric Model". In: *Geophysical Research Letters* 49.21, e2021GL096337. ISSN: 0094-8276, 1944-8007. DOI: 10.1029/2021GL096337.

URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021GL096337 (visited on 02/27/2024).

Joly, Daniel et al. (June 18, 2010). "Les types de climats en France, une construction spatiale". In: *Cybergeo: European Journal of Geography*. Publisher: CNRS-UMR Géographie-cités 8504. ISSN: 1278-3366. DOI: 10.4000/cybergeo.23155. URL: https://journals.openedition.org/cybergeo/23155 (visited on 02/27/2024).

Kanner, Jenna et al. (Oct. 1, 2020). "Ambient temperature and stillbirth: Risks associated with chronic extreme temperature and acute temperature change". In: *Environmental Research* 189, p. 109958. ISSN: 0013-9351. DOI: 10.1016/j.envres.2020.109958. URL: https://www.sciencedirect.com/science/article/pii/S0013935120308537 (visited on 12/12/2023).

Keller, Richard C. (2015). *Fatal isolation: the devastating Paris heat wave of 2003*. Chicago: University of Chicago Press. 244 pp. ISBN: 978-0-226-25111-0.

Klinenberg, Eric (2002). *Heat wave: a social autopsy of disaster in Chicago*. Chicago London: Univ. of Chicago Press. 305 pp. ISBN: 978-0-226-44321-8.

Kulkarni, Sharda and Kaustubh Kulkarni (2023). "Global warming: impact on human fertility". In: *Amrita J Med* 19.2, p. 94. ISSN: 0975-9662. DOI: 10.4103/AMJM.AMJM_24_23. URL: https://journals.lww.com/10.4103/AMJM.AMJM_24_23 (visited on 12/11/2023).

Kumar, Naina and Amit Kant Singh (2022). "Impact of environmental factors on human semen quality and male fertility: a narrative review". In: *Environ Sci Eur* 34.1, p. 6. ISSN: 2190-4707, 2190-4715. DOI: 10.1186/s12302-021-00585-w. URL: https://enveurope.springeropen.com/articles/10.1186/s12302-021-00585-w (visited on 07/04/2023).

Laaidi, Karine et al. (Feb. 2012). "The Impact of Heat Islands on Mortality in Paris during the August 2003 Heat Wave". In: *Environmental Health Perspectives* 120.2. Publisher: Environmental Health Perspectives, pp. 254–259. DOI: 10.1289/ehp.1103532. URL: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1103532 (visited on 03/01/2024).

Lam, David A. and Jeffrey A. Miron (1991). "Temperature and the Seasonality of Births". In: *Temperature and Environmental Effects on the Testis*. Ed. by Adrian

W. Zorgniotti. Vol. 286. Series Title: Advances in Experimental Medicine and Biology. Boston, MA: Springer US, pp. 73–88. ISBN: 978-1-4684-5915-9 978-1-4684-5913-5. DOI: 10.1007/978-1-4684-5913-5_7. URL: https://link.springer.com/10.1007/978-1-4684-5913-5_7 (visited on 04/17/2024).

Lam, David A. and Jeffrey A. Miron (1996). "The effects of temperature on human fertility". In: *Demography* 33.3, pp. 291–305. ISSN: 0070-3370, 1533-7790. DOI: 10.2307/2061762. URL: https://read.dukeupress.edu/demography/article/33/3/291/170640/The-effects-of-temperature-on-human-fertility (visited on 04/17/2024).

Lam, David A., Jeffrey A. Miron, and Ann Riley (1994). "Modeling Seasonality in Fecundability, Conceptions, and Births". In: *Demography* 31.2, pp. 321–346. ISSN: 0070-3370, 1533-7790. DOI: 10.2307/2061888. URL: https://read.dukeupress.edu/demography/article/31/2/321/170937/Modeling-Seasonality-in-Fecundability-Conceptions (visited on 04/17/2024).

Legun, Katharine et al. (2020). *The Cambridge handbook of environmental sociology*. Cambridge New York (N.Y.): Cambridge University Press. ISBN: 978-1-108-42932-0 978-1-108-42933-7.

Leridon, Henri (1973). *Natalité, saisons et conjoncture économique*. 66. INED.

Lesthaeghe, Ron (2010). "The Unfolding Story of the Second Demographic Transition". In: *Population & Development Rev* 36.2, pp. 211–251. ISSN: 0098-7921, 1728-4457. DOI: 10.1111/j.1728-4457.2010.00328.x. URL: https://onlinelibrary.wiley.com/doi/10.1111/j.1728-4457.2010.00328.x (visited on 05/01/2024).

Louchart, Philippe (2021). *Baisse des naissances et de la fécondité : l'Île-de-France, région la moins touchée*. L'Institut Paris Region. URL: https://www.institutparisregion.fr/societe-et-habitat/les-franciliens/baisse-des-naissances-et-de-la-fecondite-lile-de-france-region-la-moins-touchee/.

Marteleto, Letícia J., Alexandre Gori Maia, and Cristina Guimarães Rodrigues (2023). "Climate and fertility amid a public health crisis". In: *Population Studies*. Publisher: Routledge, pp. 1–22. ISSN: 0032-4728. DOI: 10.1080/00324728.2023.2228288. URL: https://doi.org/10.1080/00324728.2023.2228288.

Maslow, Abraham H. (1954). *Motivation and personality*. 1st ed. New York: Harper and Row. 293 pp. ISBN: 978-0-06-041987-5.

McDonald, Peter (2000). “Gender Equity in Theories of Fertility Transition”. In: *Population and Development Review* 26.3, pp. 427–439. ISSN: 00987921, 17284457. URL: http://www.jstor.org/stable/172314 (visited on 04/30/2024).

McElroy, Sara et al. (Jan. 1, 2022). “Extreme heat, preterm birth, and stillbirth: A global analysis across 14 lower-middle income countries”. In: *Environment International* 158, p. 106902. ISSN: 0160-4120. DOI: 10.1016/j.envint.2021.106902. URL: https://www.sciencedirect.com/science/article/pii/S0160412021005274 (visited on 12/12/2023).

Météo-France (Aug. 9, 2022). *Bilan climatique de l'été 2022*. Méteo-France. URL: https://meteofrance.fr/sites/meteofrance.fr/files/files/editorial/Bilan_complet_ete_2022_12102022.pdf.

– (July 6, 2023a). *Canicule, vague ou pic de chaleur ?* Méteo-France. URL: https://meteofrance.com/actualites-et-dossiers/comprendre-la-meteo/temperature/comment-les-climatologues-evaluent-vagues-chaleur-canicules.

– (Sept. 22, 2023b). *Le climat en France métropolitaine*. Méteo-France. URL: https://meteofrance.com/comprendre-climat/france/le-climat-en-france-metropolitaine.

– (July 21, 2023c). *Météo : vague de chaleur dans le Sud-Est*. URL: https://meteofrance.com/actualites-et-dossiers/actualites/meteo-vague-de-chaleur-dans-le-sud-est.

– (Sept. 28, 2023d). *Vagues de chaleur et changement climatique*. URL: https://meteofrance.com/changement-climatique/observer/changement-climatique-et-vagues-de-chaleur.

Ministère du Travail, de la Santé et des Solidarités (2023). *Chaleur et canicule au travail : les précautions à prendre*. Ministère du Travail, de la Santé et des Solidarités. URL: https://travail-emploi.gouv.fr/sante-au-travail/prevention-des-risques-pour-la-sante-au-travail/article/chaleur-et-canicule-au-travail-les-precautions-a-prendre.

Monk, R. C., David Easton, and Corinne S. Schelling (May 1992). "Divided Knowledge: Across Disciplines, Across Cultures." In: *Contemporary Sociology* 21.3, p. 393. ISSN: 00943061. DOI: 10.2307/2076318. URL: http://www.jstor.org/stable/2076318?origin=crossref (visited on 02/22/2024).

Murage, Peninah, Shakoor Hajat, and R. Sari Kovats (Dec. 2017). "Effect of night-time temperatures on cause and age-specific mortality in London". In: *Environmental Epidemiology* 1.2, e005. ISSN: 2474-7882. DOI: 10.1097/EE9.0000000000000005. URL: https://journals.lww.com/01984727-201712000-00001 (visited on 02/22/2024).

Myers, Samuel and Howard Frumkin (2020). *Planetary health: protecting nature to protect ourselves*. Washington: Island Press. ISBN: 978-1-61091-966-1.

Neyer, Gerda et al. (2013). *The demography of Europe*. New York: Springer. ISBN: 978-90-481-8977-9.

Oxford Reference (n.d.). *Rossby waves*. In: *Oxford Reference*. Vol. A Dictionary of Earth Sciences. URL: https://www.oxfordreference.com/display/10.1093/oi/authority.20110803100429591.

Papon, Sylvain (2020). *En un siècle, le pic des naissances s'est décalé de l'hiver à l'été et s'est atténué*. INSEE FOCUS 204. INSEE.

Petoukhov, Vladimir et al. (Apr. 2, 2013). "Quasiresonant amplification of planetary waves and recent Northern Hemisphere weather extremes". In: *Proceedings of the National Academy of Sciences* 110.14. Publisher: Proceedings of the National Academy of Sciences, pp. 5336–5341. DOI: 10.1073/pnas.1222000110. URL: https://www.pnas.org/doi/abs/10.1073/pnas.1222000110 (visited on 02/27/2024).

Philipov, Dimiter, Aart C. Liefbroer, and Jane E. Klobas, eds. (2015). *Reproductive Decision-Making in a Macro-Micro Perspective*. Dordrecht: Springer Netherlands. ISBN: 978-94-017-9400-8 978-94-017-9401-5. DOI: 10.1007/978-94-017-9401-5. URL: https://link.springer.com/10.1007/978-94-017-9401-5 (visited on 02/21/2024).

Régnier-Loilier, Arnaud (2007). *Avoir des enfants en France: désirs et réalités*. Les cahiers de l'INED 159. OCLC: ocn123229119. Paris: Institut national d'études démographiques. 267 pp. ISBN: 978-2-7332-0159-6.

– (2010). "Évolution de la saisonnalité des naissances en France de 1975 à nos jours:" in: *Population* Vol. 65.1, pp. 147–189. ISSN: 0032-4663. DOI: 10.3917/popu.1001.0147. URL: https://www.cairn.info/revue-population-2010-1-page-147.htm?ref=doi (visited on 02/22/2024).

Régnier-Loilier, Arnaud and Jean-Marc Rohrbasser (Feb. 25, 2011). "Y a-t-il une saison pour faire des enfants ?:" in: *Population & Sociétés* N° 474.1, pp. 1–4. ISSN: 0184-7783. DOI: 10.3917/popsoc.474.0001. URL: https://www.cairn.info/revue-population-et-societes-2011-1-page-1.htm?ref=doi (visited on 02/22/2024).

Reynaud, Dider (Dec. 5, 2022). *Fécondité selon le niveau de vie : une nouvelle estimation*. 72. URL: https://www.insee.fr/fr/statistiques/6441218.

Salamanca, F. et al. (May 27, 2014). "Anthropogenic heating of the urban environment due to air conditioning". In: *JGR Atmospheres* 119.10, pp. 5949–5965. ISSN: 2169-897X, 2169-8996. DOI: 10.1002/2013JD021225. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2013JD021225 (visited on 04/04/2024).

Santé Publique France (June 2023a). *Canicule: Dispositif d'Alerte et de Surveillance et Dispositif de Prévention de Santé Publique France*. Santé Publique France.

– (June 2023b). *Estimation de la fraction de la mortalité attribuable à l'exposition de la population générale à la chaleur en France métropolitaine. Application à la période de surveillance estivale (1er juin -15 septembre) 2014-2022*. Santé Publique France. URL: https://www.santepubliquefrance.fr/determinants-de-sante/climat/fortes-chaleurs-canicule/documents/rapport-synthese/estimation-de-la-fraction-de-la-mortalite-attribuable-a-l-exposition-de-la-population-generale-a-la-chaleur-en-france-metropolitaine.-application-a.

Schmucki, Reto (2023). "climateExtract: Extract and manipulate daily gridded observational dataset of European climate (E-OBS) provided by ECAD". In: *R package version 1.27*. URL: https://github.com/RetoSchmucki/climateExtract.

Seiver, Daniel A. (1985). "Trend and variation in the seasonality of U.S. fertility, 1947–1976". In: *Demography* 22.1, pp. 89–100. ISSN: 0070-3370, 1533-7790. DOI: 10.2307/2060988. URL: https://read.dukeupress.edu/demography/article/22/1/89/171580/Trend-and-variation-in-the-seasonality-of-U-S (visited on 04/17/2024).

– (1989). "Seasonality of fertility: New evidence". In: *Popul Environ* 10.4, pp. 245–257. ISSN: 0199-0039, 1573-7810. DOI: 10.1007/BF01255839. URL: http://link.springer.com/10.1007/BF01255839 (visited on 04/17/2024).

Shepherd, Theodore G. (Oct. 2014). "Atmospheric circulation as a source of uncertainty in climate change projections". In: *Nature Geosci* 7.10, pp. 703–708. ISSN: 1752-0894, 1752-0908. DOI: 10.1038/ngeo2253. URL: https://www.nature.com/articles/ngeo2253 (visited on 02/27/2024).

Sovacool, Benjamin K. et al. (May 1, 2021). "Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions". In: *Renewable and Sustainable Energy Reviews* 141, p. 110759. ISSN: 1364-0321. DOI: 10.1016/j.rser.2021.110759. URL: https://www.sciencedirect.com/science/article/pii/S136403212100054X.

Testa, Maria Rita (Sept. 1, 2014). "On the positive correlation between education and fertility intentions in Europe: Individual- and country-level evidence". In: *Advances in Life Course Research* 21, pp. 28–42. ISSN: 1569-4909. DOI: 10.1016/j.alcr.2014.01.005. URL: https://www.sciencedirect.com/science/article/pii/S1040260814000069.

The World Bank (2024). *The World Bank Data Bank*. URL: https://data.worldbank.org/indicator/SP.DYN.TFRT.IN.

Thonneau, P. et al. (Aug. 1, 1998). "Occupational heat exposure and male fertility: a review". In: *Human Reproduction* 13.8, pp. 2122–2125. ISSN: 0268-1161, 1460-2350. DOI: 10.1093/humrep/13.8.2122. URL: https://academic.oup.com/humrep/article-lookup/doi/10.1093/humrep/13.8.2122 (visited on 05/06/2024).

Tierney, Kathleen J., ed. (1994). *Disasters, collective behavior, and social organization*. Newark : London ; Cranbury, NJ: University of Delaware Press ; Associated University Presses. 378 pp. ISBN: 978-0-87413-498-8.

Toulemon, Laurent and Maria Rita Testa (Sept. 2005). "Fertility intentions and actual fertility: A complex relationship". In: *Population & Societes*. Bulletin Mensuel D'Information de L'Institut National D'Études Démographiques (No. 415). URL: https://www.ined.fr/fichier/s_rubrique/18747/publi_pdf2_pop.and.soc.english.415.en.pdf.

Tuel, Alexandre and Elfatih A. B. Eltahir (Nov. 1, 2021). "Mechanisms of European Summer Drying under Climate Change". In: *Journal of Climate* 34.22. Publisher: American Meteorological Society Section: Journal of Climate, pp. 8913–8931. ISSN: 0894-8755, 1520-0442. DOI: 10.1175/JCLI-D-20-0968.1. URL: https://journals.ametsoc.org/view/journals/clim/34/22/JCLI-D-20-0968.1.xml (visited on 02/27/2024).

UNEP (n.d.). *Global Warming Potential (GWP) of Refrigerants: Why are Particular Values Used?* Montreal Protocol Annex C and Annex F. United Nations Environment Programme. URL: https://wedocs.unep.org/bitstream/handle/20.500.11822/28246/7789GWPRef_EN.pdf?sequence=2&isAllowed=y#:~:text=The%20GWPs%20of%20commonly%20used,warming%20effects%20of%20different%20gases..

Van Donkelaar, Aaron et al. (Nov. 16, 2021). "Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty". In: *Environ. Sci. Technol.* 55.22, pp. 15287–15300. ISSN: 0013-936X, 1520-5851. DOI: 10.1021/acs.est.1c05309. URL: https://pubs.acs.org/doi/10.1021/acs.est.1c05309 (visited on 04/25/2024).

Wesselink, Amelia K et al. (Mar. 27, 2020). "Seasonal patterns in fecundability in North America and Denmark: a preconception cohort study". In: *Human Reproduction* 35.3, pp. 565–572. ISSN: 0268-1161. DOI: 10.1093/humrep/dez265. URL: https://doi.org/10.1093/humrep/dez265 (visited on 05/04/2023).

White, Rachel H. et al. (2022). "From Atmospheric Waves to Heatwaves: A Waveguide Perspective for Understanding and Predicting Concurrent, Persistent, and Extreme Extratropical Weather". In: *Bulletin of the American Meteorological So-*

ciety 103.3. Publisher: American Meteorological Society Section: Bulletin of the American Meteorological Society, E923–E935. ISSN: 0003-0007, 1520-0477. DOI: 10.1175/BAMS-D-21-0170.1. URL: https://journals.ametsoc.org/view/journals/bams/103/3/BAMS-D-21-0170.1.xml (visited on 02/27/2024).

Wilde, Joshua, Bénédicte H. Apouey, and Toni Jung (Aug. 2017). "The effect of ambient temperature shocks during conception and early pregnancy on later life outcomes". In: *European Economic Review* 97, pp. 87–107. ISSN: 00142921. DOI: 10.1016/j.euroecorev.2017.05.003. URL: https://linkinghub.elsevier.com/retrieve/pii/S0014292117300892 (visited on 2024).

Wisner, Benjamin, ed. (2004). *At risk: natural hazards, people's vulnerability, and disasters*. 2nd ed. London ; New York: Routledge. 471 pp. ISBN: 978-0-415-25215-7 978-0-415-25216-4.

WMO (2023). *Guidelines on the Definition and Characterization of Extreme Weather and Climate Events*. World Meteorological Organization. URL: https://library.wmo.int/doc_num.php?explnum_id=11535.

World Health Organization (2014). *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s*. Section: viii, 115 p. Geneva: World Health Organization. ISBN: 978-92-4-150769-1. URL: https://iris.who.int/handle/10665/134014 (visited on 02/21/2024).

– (2024). *Health Topics: Heat Waves*. World Health Organization. URL: https://www.who.int/health-topics/heatwaves#tab=tab_1.

Zschenderlein, Philipp et al. (2019). "Processes determining heat waves across different European climates". In: *Quarterly Journal of the Royal Meteorological Society* 145.724. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/qj.3599, pp. 2973–2989. ISSN: 1477-870X. DOI: 10.1002/qj.3599. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/qj.3599 (visited on 02/27/2024).

Appendix A

Full Results

Table A.1: Figure 4.1

	Estimate	Std. Error	Pr(>|t|)	Significance
lead(bin7, 1:3)3	0.00058	(0.001)	0.43444	
lead(bin7, 1:3)2	-0.00024	(0.001)	0.74616	
lead(bin7, 1:3)1	-0.00082	(0.001)	0.26218	
coefficients_no_lag	0.00105	(0.001)	0.15163	
lag(bin7, 1:20)1	0.00006	(0.001)	0.93204	
lag(bin7, 1:20)2	0.00079	(0.001)	0.27389	
lag(bin7, 1:20)3	0.00037	(0.001)	0.60789	
lag(bin7, 1:20)4	-0.00008	(0.001)	0.90702	
lag(bin7, 1:20)5	-0.00061	(0.001)	0.43682	
lag(bin7, 1:20)6	0.00102	(0.001)	0.25066	
lag(bin7, 1:20)7	-0.00016	(0.001)	0.86608	
lag(bin7, 1:20)8	-0.00023	(0.001)	0.80886	
lag(bin7, 1:20)9	-0.00261	(0.001)	0.00510	*
lag(bin7, 1:20)10	-0.00256	(0.001)	0.00597	*
lag(bin7, 1:20)11	0.00107	(0.001)	0.25214	
lag(bin7, 1:20)12	-0.00012	(0.001)	0.89686	
lag(bin7, 1:20)13	0.00012	(0.001)	0.89754	
lag(bin7, 1:20)14	0.00115	(0.001)	0.22293	
lag(bin7, 1:20)15	-0.00026	(0.001)	0.77601	
lag(bin7, 1:20)16	-0.00063	(0.001)	0.50797	
lag(bin7, 1:20)17	0.00006	(0.001)	0.93938	
lag(bin7, 1:20)18	0.00005	(0.001)	0.93644	
lag(bin7, 1:20)19	-0.00052	(0.001)	0.43986	
lag(bin7, 1:20)20	0.00116	(0.001)	0.08622	

* $p < 0.05$

Table A.2: Figure 4.2

	Estimate	Std. Error	Pr(>|t|)	Significance
lag(bin1, 1:20)9	0.00006	0.00041	0.87467	
lag(bin2, 1:20)9	0.00037	0.00030	0.21849	
lag(bin3, 1:20)9	0.00018	0.00021	0.39978	
lag(bin5, 1:20)9	-0.00040	0.00021	0.06089	
lag(bin6, 1:20)9	-0.00141	0.00036	0.00011	*
lag(bin7, 1:20)9	-0.00261	0.00093	0.00510	*

* $p < 0.05$

Table A.3: Figure 4.3

	Estimate	Std. Error	Significance
1975_1997	−0.0018312270	0.0005661026	*
1998_2020	−0.0007889260	0.0003237058	*

* $p < 0.05$

Table A.4: Figure 4.3: Hot Regions

	Estimate	Std. Error	Significance
bin 1	-0.0001153073	0.0007015791	
bin 2	0.0002145030	0.0004956750	
bin 3	0.0001284375	0.0003540748	
bin 5	−0.0002972570	0.0003596909	
bin 6 and 7	−0.0015510874	0.0005879827	*

* $p < 0.05$

Table A.5: Figure 4.3: Cold Regions

	Estimate	Std. Error	Significance
bin 1	0.0002613822	0.0005396571	
bin 2	0.0003557539	0.0004047828	
bin 3	0.0000813206	0.0002854520	
bin 5	−0.0007780645	0.0003045722	*
bin 6 and 7	−0.0017107445	0.0005115878	*

* $p < 0.05$

Table A.6: Figure 4.5

	Estimate	Std. Error	Significance
Alsace	-0.010525679	0.002428236	***
Aquitaine	-0.00866330	0.00170470	***
Auvergne	-0.00730551	0.00280362	**
Basse-Normandie	-0.01080102	0.00513978	*
Bourgogne	-0.01034144	0.00202013	***
Bretagne	-0.00857849	0.00449125	
Centre	-0.00820817	0.00199059	***
Champagne-Ardennes	-0.01525685	0.00276921	***
Corse	-0.00791064	0.00233108	***
Franche-Comté	-0.00834894	0.00317710	**
Haute-Normandie	-0.00708753	0.00387228	
Île-de-France	-0.00559633	0.00153935	***
Languedoc-Roussillon	-0.006389656	0.001834775	***
Limousin	-0.00734680	0.00333691	*
Lorraine	-0.00858837	0.00231606	***
Midi-Pyrénées	-0.006765825	0.001968787	***
Nord-Pas-de-Calais	-0.011141787	0.003678412	**
Pays de la Loire	-0.00786784	0.00233804	***
Picardie	-0.012294043	0.002376152	***
Poitou-Charentes	-0.00633751	0.00191106	***
Provence-Alpes-Côte-d'Azur	-0.00907736	0.00233240	***
Rhône-Alpes	-0.006311981	0.004089285	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.7: Figure 4.6

	Estimate	Std. Error	Significance
Alsace	-0.005189931	0.000646949	***
Aquitaine	-0.00417832	0.00063320	***
Auvergne	-0.00476573	0.00082548	***
Basse-Normandie	-0.00574908	0.00090992	***
Bourgogne	-0.00466595	0.00067879	***
Bretagne	-0.00488816	0.00084201	***
Centre	-0.005365748	0.000632001	***
Champagne-Ardennes	-0.00581681	0.00072369	***
Corse	-0.00529672	0.00135407	***
Franche-Comté	-0.00485487	0.00084032	***
Haute-Normandie	-0.00466570	0.00072613	***
Île-de-France	-0.00456252	0.00046736	***
Languedoc-Roussillon	-0.004158072	0.000610993	***
Limousin	-0.00438253	0.00092904	***
Lorraine	-0.00486472	0.00065158	***
Midi-Pyrénées	-0.003867002	0.000607884	***
Nord-Pas-de-Calais	-0.00495114	0.00056159	***
Pays de la Loire	-0.00433399	0.00069995	***
Picardie	-0.00514422	0.00060861	***
Poitou-Charentes	-0.00451830	0.00070181	***
Provence-Alpes-Côte-d'Azur	-0.00487897	0.00045102	***
Rhône-Alpes	-0.00553033	0.00059252	***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.8: Figure 4.9

	Estimate	Std. Error	Significance
bin 1	0.00017153911	0.00041014576	
bin 2	0.00044189948	0.00029767984	
bin 3	0.00022818816	0.00020931361	
bin 5	-0.00040394196	0.00021413415	
bin 6 and 7: Pic	-0.00129847992	0.00051118791	*
bin 6 and 7: Heat Wave	-0.00142259413	0.00038448594	*

* $p < 0.05$

Table A.9: Figure 4.12

	Estimate	Std. Error	Significance
Lead 3	0.0023659590	0.003049466	
Lead 2	-0.0006076995	0.003066598	
Lead 1	-0.0039399213	0.003054970	
0	-0.0029935663	0.003062694	
Lag 1	-0.0035436236	0.003065828	
Lag 2	-0.0019531857	0.003047876	
Lag 3	-0.0033720324	0.003043882	
Lag 4	-0.0100749444	0.003048426	*
Lag 5	0.0035087303	0.003090068	
Lag 6	-0.0073934612	0.003308271	*
Lag 7	-0.0062654751	0.004292440	
Lag 8	-0.0097489699	0.004285426	*
Lag 9	-0.0127287252	0.004321734	*
Lag 10	-0.0156701833	0.004322102	*
Lag 11	-0.0064952729	0.004318812	
Lag 12	-0.0083827657	0.004322591	
Lag 13	-0.0109698117	0.004327332	*
Lag 14	-0.0051910180	0.004327025	
Lag 15	-0.0047133845	0.004318414	
Lag 16	-0.0111388394	0.004315762	*
Lag 17	-0.0081061355	0.004154965	
Lag 18	-0.0028084706	0.003492193	
Lag 19	0.0057419360	0.002823361	*
Lag 20	0.0074160699	0.002813500	*

* $p < 0.05$