Working Paper No. 588

The Weaker Sex? Vulnerable Men, Resilient Women, and Variations in Sex Differences in Mortality Since 1900

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September 2016

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Acknowledgements

We are very grateful to Cai Yong for sharing with us his micro data on county-specific S70 and GDP per capita derived from China's 2000 census data.

Published in *Social Science and Medicine: Population Health*, 2016. Published version available at http://aparc.fsi.stanford.edu/sites/default/files/ssm_population_health_2_512-524.pdf

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Running head: **Variations in Sex Differences in Mortality**

Abstract. Sex differences in mortality (SDIM) vary over time and place as a function of social, health, and medical circumstances. The magnitude of these variations, and their response to large socioeconomic changes, suggest that biological differences cannot fully account for sex differences in survival. We develop a set of empiric observations about SDIM with which any theory will have to contend. We draw on a wide swath of mortality data, including probability of survival to age 70 by county in the United States, the Human Mortality Database data for 18 high-income countries since 1900, and mortality data within and across developing countries over time periods for which reasonably reliable data are available. We show that as societies develop, M/F survival first declines and then increases, a "SDIM transition" embedded within the well-described demographic and epidemiologic transition. After the onset of this transition, cross-sectional variation in SDIM exhibits a consistent pattern of female resilience to mortality under adversity, which strengthens over time.

Introduction

Decades of research have found that women generally outlive men in developed countries (Kalben 2002; Verbrugge 2012; Waldron 1976). More recently, it has become evident that not only do women have longer life expectancy from birth (LE) in such societies, but their mortality rates at every age are lower, starting *in utero* (Catalano and Bruckner 2006). So pervasive are these observations that some demographers now equate the longevity of the human *species,* at any given time and place, with the highest observed LE of women (Horton and Lo 2013; Oeppen and Vaupel 2002). Yet sex differences in mortality (SDIM) vary widely over time and place. In this paper we explore this variation in search of insights into why women live longer. In particular, we are motivated by the hope such insights will reveal opportunities to reduce the excess mortality of men.

Efforts to explain SDIM are not new (Kruger and Nesse 2004; MacIntyre et al. 1996; Møller et al. 2009; Taylor et al. 2009; Waldron 1983; Waldron 1976; Yang and Kozloski 2012), and can be briefly categorized into three broad schools of thought. First is the notion of selective female survival advantage on a "hard-wired" basis (Drevenstedt et al. 2008; Liu et al. 2014; Mage and Donner 2006). Second is the idea that socially mediated behavioral differences explain the gap—human males in virtually every society take more risks, are more violent and behave in ways that make them more prone to accidental injury, while females are more likely to be health-seeking (Case and Paxson 2005; Cook et al. 2011; Rahman et al. 1994; Concha-Barrientos et al. 2004; Cutler et al. 2011; Ezzati et al. 2008; Gabel and Gerberich 2002; Hunter and Reddy 2013; Kalben 2002; McCartney et al. 2011; Norström and Razvodovsky 2010; Tomkins et al. 2012 ; Bhattacharya et al. 2012; McCartney et al. 2011; Preston and Wang 2011; Gillespie et al. 2014). A third perspective views social difference as one manifestation of biologically driven behavioral difference, so-called sociobiology; by this perspective, biologic differences of greatest interest express themselves in different social behaviors which are mutable, at least in theory (Gorman and Read 2007; Ristvedt 2014; Umberson and Montez 2010; Braveman et al. 2011; Chu and Lee 2012).

In this paper we do not attempt to weigh the evidence for each of these mutually compatible pathways; rather we describe and contrast patterns of SDIM across time and place with which any theory will ultimately have to contend. We begin our investigation with the data that is of highest quality: the contemporary developed world. We then study patterns of SDIM using a wide swath of available mortality data, within and between developing and developed countries and over the time periods for which reasonably reliable data are available. Of particular interest is the observed relationship between SDIM and demographic and epidemiologic transition (Mooney 2002; Omran 1971), since this relationship facilitates comparison of changes in SDIM in developed countries—from which almost all published work on this subject has emerged—to those presently evolving in developing countries at an earlier phase of transition. We limit explanatory analyses to correlations and basic regressions, using markers of social condition within and between countries based entirely on availability and generalizability; it is not our intent to test the causal relationship between any specific factor(s) and SDIM, but rather to identify patterns to encourage such testing.

The paper is organized as follows. After describing our data sources and methods, we examine variation in probability of survival to age 70 (S_{70}) across US counties, extending previous research (Cullen et al. 2012) and showing that women consistently exhibit greater survival "resilience" to social adversity. Part II explores changes in M/F mortality across now-developed countries since 1900, and Part III examines the evolution of SDIM in the contemporary developing world. Part IV turns to the Former Soviet Union (FSU) and Eastern Europe to exploit the great natural experiment unleashed by Gorbachev's reforms and the subsequent "transformational recessions." The final section summarizes our observations about variation in SDIM over time and place, then returns to the question of why women live longer than men and the implications for reducing excess male mortality.

Data and methods

We measure mortality as survival to age 70 (S_{70}) or LE. We prefer the former because of its reliability of estimation in small populations for which rates of mortality among older age groups are unstable. However, for many populations and subpopulations of *a priori* interest, we must rely on published estimates of LE, secondarily derived. As our measure of differential mortality we have chosen M/F (either M/F_{70} where possible, or M/F_{LE}) as our outcome measure. The preference for M/F as a statistic is twofold: first, it is almost uniformly between 0.6 and 1 in the data, conferring some ease of presentation; and second, it is consistent with the evolving demographic concept that in high income, low fertility societies, female mortality represents at a place and time the species longevity “gold standard,” a target we hope men could emulate, i.e. that M/F_{70} or M/F_{LE} would approach unity. However, it should be noted that in other societies—particularly those plagued by poverty and high maternal mortality and/or rampant discrimination against women—a M/F_{70} or M/F_{LE} approaching or exceeding unity appears to imply the opposite: a red flag signaling that female survival is far below potential.

Despite the noted similarities between M/F_{70} or M/F_{LE}—and the strong positive correlation between them — the metrics are not interchangeable. The meaning of an M/F_{LE} of 0.90, for example, is not the same as an M/F_{70} of the same numeric value: the former is about average in our LE data sets, the latter so high as to be seen only in the very wealthiest and poorest of populations.

Regarding choice of data sources, we decided, for quality and practical reasons to confine most of our study to the last 5 decades, a time period for which reasonable mortality data and some relevant covariate data are available. The major exception was data from the Human Mortality Database, which enables a look back to 1900 for 18 now high-income countries.

Others have previously published the average life expectancy for 187 countries by decade since 1970 (Wang et al. 2012). We grouped these countries using data from the Global Burden of Disease project (Lozano et al. 2012). Specifically, we defined five groups of countries (Group 1 most developed) based on the country’s 2010 Human Development Index, modified to exclude LE as a core measure to avoid autocorrelation in our analyses, as discussed below. The decision to classify based on stage of development at the *end* of the observation period, not the beginning, was arbitrary, and was designed to facilitate observation of SDIM patterns with foreknowledge of the countries’ economic/social development “endpoint.” Likewise we separated out the former Warsaw Pact countries, designated at Group 1E, because of their distinct survival and SDIM patterns. The countries classified in each of the five groups are listed in Supplemental Table 1.

A third *a priori* decision was to exclude from detailed consideration period-place combinations where maternal mortality remains very high and where epidemiologic and demographic transition has not yet begun. Therefore we have not analyzed data on M/F in any countries before 1900 or in contemporary Group 4 countries—the world's very poorest—except for a single comparison with developing countries that *have* entered transition.

Finally, we have largely refrained from examining cause-specific mortality data because of substantial limitations in its availability and quality going back in time, although we return to discuss this pathway for SDIM in the final section.

The specific sources of data for each section of the paper are described in Appendix A.

Part I: M/F in the US and other Group 1 Countries in 2010

The left panel of Figure 1 shows the distribution of S_{70} for white men and women in the US by county. The means for the populations are 0.67 for men and 0.82 for women and the standard deviations 0.05 and 0.03, respectively. As can be seen, women enjoy a sharp advantage and a smaller variance than men. As previously noted, within-sex geographic variation in US mortality can be largely explained by a small set of social, environmental and health care-related variables, as can between-race differences (Cullen et al. 2012), but these same variables do not explain the gulf *between* the sexes. Moreover, all are less than unity—there is no US county in which males have equal or better survival than females, though there are some counties for which the ratio approaches 1.

Figure 2 A-C shows that women consistently exhibit greater survival "resilience" to social adversity. More or less identical relationships emerge with respect to percent in poverty, per capita income, or low educational attainment. Although survival is associated with each of these social measures, men are far more "elastic" in response (which is consistent with the hypothesis that men are more vulnerable to adverse social circumstances). OLS regressions, shown in Table 1, describe the relationships quantitatively. Though each of the four variables shown is itself a potent univariate predictor of mortality, tobacco use and obesity correlate weakly with SDIM after controlling for other covariates and add little to the model's predictive power. Conditional on the other variables, M/F smoking ratios also appear minimally related to M/F_{70} (Figure S1).

Counties in the 16 Southern states have lower M/F_{70} after adjusting for the other covariates. The occupational similarity index explains substantial variation (Figure 2D), an observation to which we return in the discussion.

The cross-sectional variation in M/F among and within other Group 1 countries reveals comparable relationships between SDIM and indicators of SES. Switching to M/F_{LE}, Figure 3 shows that log per capita GDP is strongly correlated with M/F_{LE} across high-income countries. This same relationship appears to hold among geopolitical regions within Spain and Japan (Fig S2). Ecologic analyses of income strata in Canada and Denmark mirror this as well (Helweg-Larsen and Juel 2000; Trovato and Lalu 2005); to our knowledge there are no counter-examples among high-income countries.

Part II: M/F in the US and other Group 1 Countries over Time

We begin our inspection of the longitudinal change in M/F after World War II, when mortality data are more robust than for earlier periods. Figure 4 shows the respective changes in M/F_{70} for all of the Group 1 countries. Japan exhibits a distinctive downward trend, but all of the other countries show a consistent "U" with the nadir somewhere between 1970 and 1985.

In Figure 5 we show in cross-section the relationship in the US between M/F and per capita GDP (by State because of availability) at the nadir of M/F (around 1970) and forward to the present. This figure suggests that the cross-sectional "female resilience" pattern was already ensconced long before 1970 and has persisted. Striking too, although the slope appears to remain more or less unchanged over time, the correlation strengthens in both plots. Comparing Group 1 countries with each other during this 40-year period (Figure S3), the same pattern is evident.

Next we examine the available data from the early 20th century to observe (available) Group 1 countries during their epidemiologic transition (Fink 2013; Omran 1971). Figure 6 reveals this was a period of steady M/F decline in the U.S. and other Group 1 countries for which we have data, using weighted averages and weighting by log (population). This downward trend in M/F reflects gradually increasing relative female survival. Notably, several countries—including the United States—started the 20th century with an M/F_{LE} ratio exceeding 1.0, suggesting that before the demographic and epidemiologic transition women suffered a mortality *disadvantage.*

Figure 7, in which we (reluctantly) use average LE as the independent variable for lack of a consistent measure for GDP or human development, shows how M/F varies across the 18 Group 1 countries in each decade between 1900 and 2010. In the first two decades the *reverse* of the later resilience pattern is evident—women did relatively best in the higher LE countries—followed by a flattening of the relationship by 1920 before the familiar "resilience" pattern emerges and strengthens over time, reinforcing the picture we observed in the US (Fig. 5) and in the later decades for Group 1 countries (Fig. S3).

Part III: M/F in developing countries (LMIC's) in Groups 2, 3 and 4

Moving to the low- and middle-income countries (LMICs), three different patterns are salient, depicted in Figure 8. In Group 2 (the most developed countries after Group 1, including such countries as Brazil, Mexico, Thailand and South Africa), we see a steady decline in M/F_{LE} throughout the period 1970-2010, resembling the Group 1 countries between 1900 and 1970 with a suggestion of a "turnaround" in 2000 reminiscent of the trough in Group 1 countries 2-3 decades before. Group 3 countries, by contrast, show high levels of M/F_{LE} before the decline that starts around 1990-2000. M/F in Group 4 countries—the world's poorest—remains, by contrast, high throughout the period, and for a few countries actually exceeds 1.0 (Sub-Saharan African countries, data not shown) (Lozano et al. 2012).

Figure 9 includes regressions of the relationship between M/F_{LE} and average LE in cross-section by decade for countries in Groups 2 and 3. It appears that for Group 2 countries, about a decade after the M/F begins to decline, the pattern of "resilience" for women begins to emerge and strengthens in extent of variation explained; by 2010 the relationship is robust, not unlike what was observed between 1900 and 1980 for Group 1 countries. For the Group 3 countries, the relationship remains flat through 1990, after which M/F starts to fall. The cross-sectional resilience pattern emerges about a decade thereafter, by 2010 explaining about 50 percent of the variance. For Group 4 countries M/F stays very high and in cross-section shows no clear relationship to GDP (data not shown) for reasons we explore further below.

The “switch” in pattern is well illustrated in Figure S5, which shows recent within-country variation in cross section for two populous countries for which reasonable quality data are available. The right panel depicts Brazil, a Group 2 country now of middle income, revealing the “resilience” pattern of M/F_{LE}, here in a scatter against percent in poverty, similar to the pattern which emerged in Group 1 countries several decades earlier. Sri Lanka, on the other hand, is a Group 3 country which as recently as 1963 still had sufficiently high rates of maternal mortality that *national* rates of mortality were higher for women ages 15-40 than for men (Fink 2013; Omran 1971). This pattern provides a hint that the “pre-resilience” pattern of M/F_{LE}, reminiscent of that in Group 1 countries in 1900-1910, may reflect persistent excessive maternal mortality in the poorer parts of developing countries early in their transition. This same pattern would appear to explain the high M/F in the Group 4 countries, consistent with high maternal mortality (Figure S6); by contrast, maternal mortality rates are detectable but low in Group 3 countries, and much lower in Groups 1 and 2 (Hogan et al. 2010).

That the lingering effects of maternal mortality may partially explain the pattern of female resilience emerging a decade or two after national rates of M/F start to fall is further suggested by modern China, a country that would have ranked as a Group 3 country as recently as 1980 but has become Group 2 (and classified as such by our schema). Figure S7 shows M/F_{70} for over 2300 county-level units in China based on county-specific life-tables calculated by Cai Yong from the year 2000 census (Cai 2005). Looking at the aggregate data (left panel) there appears to be no relationship between county log per capita GDP and M/F_{70}. Stratification by rural/urban status reveals a more nuanced picture: rural areas (middle panel) resemble the pattern observed in Sri Lanka, with the highest M/F among the poorest counties, in several cases here exceeding 1, consistent with son preference and China’s large male-to-female sex ratio at birth; whereas the urban areas (right panel) distribute more like Brazil or the US, with higher M/F_{70} in more-developed areas. Moreover, change over time is also consistent with the patterns of M/F survival noted earlier: based on census data on LE for three of the poorest provinces (Guizhou, Qinghai and Yunnan) with data extending back to 1981, average M/F_{LE} *decreased* from 0.98 in 1981 to 0.93 in 2010. By contrast, M/F_{LE} in China’s wealthiest city, Shanghai, *increased* from 0.94 in 1981 to 0.95 in 2000 (Cai 2005).

Part IV: M/F in Eastern Europe and the former Soviet Union (Group 1E)

The experience of Eastern European countries, including the former Soviet Union (FSU), adds a unique dimension to our understanding of sex differences in mortality. These nations display the lowest values for M/F of any group of countries in the world, based on the most current data available, evident from even cursory inspection of the map shown in Figure S8. Moreover, as shown vividly in Figure 10, the current situation is actually an *improvement* for men relative to the nadir seen two decades ago. The figure illustrates another remarkable feature not evident elsewhere in the world, which is *volatility of SDIM*, matched otherwise only in demographic disasters such as epidemics and wars. This observation must be viewed in the context of the enormous political change that swept this region during the 1980's and 90's, namely the liberalization of state communism during the 80's consequent to Gorbachev's policies in the USSR (associated with rapid and demonstrable improvement in the relative mortality of men), and the subsequent demise of that system in the FSU and former Warsaw Pact countries and replacement with market systems in all. This was accompanied by a "transformational recession" that depressed real standards of living for most of the population (Kornai 1994), associated with rapidly rising mortality for men for some years, while female mortality rates were less impacted, hence the plummeting M/F_{70}. For completeness we depict the somewhat "melded" experience of Germany (Figure S9). Like other non-FSU Warsaw pact countries, men faltered in the late 80's and even more so after the collapse of the Berlin wall, but since have followed a more typical "Group 1" pattern as part of greater Germany (Vogt and Kluge 2014).

Because of the historic heavier use of alcohol in this region of the world than any other, and the plausibility of its role as mediator for mortality rate gyrations, toxic levels of alcohol consumption have been the focus of much study (Gerry 2012; Mckee and Shkolnikov 2001; Murphy et al. 2006; Tulchinsky and Varavikova 1993; Weidner and Cain 2003; Zaridze et al. 2014; Zatoński 2011). Many analysts credit reduction in excess male mortality to one specific aspect of the Gorbachev reforms—alcohol consumption taxes—in the 80's, and blame the subsequent spike in male mortality on the elimination of those alcohol taxes after 1990 (see for example Bhattacharya et al. 2012); this account is consistent with the biphasic change in SDIM in the FSU during the 1980's seen in Figure 10. There is a smoother decline in M/F in the neighboring states including East Germany, states not as directly impacted by the Gorbachev alcohol controls as Russia. Comparative data exploring the statistical association between male survival decline and changes in the rate of mortality from acute intoxication among the Russian Oblasts over the two time periods 1978-88 (alcohol less available) and 1988-98 (alcohol more available) may raise the question whether alcohol was the root cause of the rapid increase in male mortality, or one of its mediators. As shown in Figure S10, the gyrations in SDIM in 6 of the 8 oblasts were accompanied by dramatic period changes in the rate of acute alcohol-related hospital deaths; however, comparable changes in M/F_{LE} occurred in the other two—the North Caucasus and South—with virtually *no* evidence of substantial acute alcohol-related deaths over the period, likely because these regions, albeit of modest comparative population size, are predominantly Muslim. This is not to suggest previous studies have inappropriately targeted the role of alcohol as a rapid and epidemic killer of men, but rather that the role of alcohol may be better viewed as mediating a relationship between social conditions and male mortality rates—seen here as M/F_{LE}—that finds differential expression in different social and geopolitical contexts. This intuition would appear to be consistent with the fact that despite an abrupt and impressive "transformational recession" in which per capita GDP nosedived, the "resilience" pattern of M/F appears moderately well preserved across the Group 1E countries (Figure S11).

Discussion

From the above observations we draw a series of ten inferences, presented roughly in the order of those least to most speculative:

1. Sex differences in mortality (SDIM) vary over time and place as a function of social and possibly medical conditions. The magnitude of these variations, and their abruptness in response to large socioeconomic changes, suggest that biological differences alone cannot fully account for observed sex differences in survival.

While many have previously observed the variation in SDIM over time and place, the assembled evidence suggests that such variation follows distinct and identifiable patterns of social change. While some of the underlying patterns are more readily explained than others (as discussed below), there would appear to be little "randomness" in M/F for any population of reasonable size to stably estimate either survival probabilities or LE (with the possible exception of the world's poorest states, for which reliable data is lacking).

2. A "SDIM transition" unfolds as part of the demographic and epidemiologic transitions, beginning with the emergence of the now near-universal "female survival advantage" (M/F survival<1), heralded by significant reductions in fertility and maternal mortality and associated causes of death during the reproductive years.

It is almost certain, though data are incomplete, that there was a time in the history of all now developed (Group 1) countries, and those now developing (Groups 2 and 3), wherein female mortality exceeded that of men. In developed countries the turning point likely occurred between the late 19th century (for northern Europe and Switzerland, for example) and 1910 (see Figure S4). In Group 2 countries this change occurred later, most likely in the mid-twentieth century (although confirmation is problematic because we do not have reliable data on these countries for this time period). We observe this same SDIM transition, occurring between 1970 and 1990, in countries less far along in development (Group 3). Tragically, in some Group 4 countries M/F>1 remains true still today. Omran in his seminal presentation of the epidemiologic transition in 1971 (Omran 1971) opines this was due to maternal mortality at a time when fertility rates were high and the combination of medical knowledge and resources insufficient to prevent frequent maternal deaths from bleeding and infection in poor countries. This conclusion would appear to be reinforced by our observations of Group 2 and 3 countries as they have entered transition, and the data on maternal mortality presented in Figure S6.

Subsequently, within each of these societies, as the survival of women begins to improve, a distinctive cross-sectional pattern emerges wherein M/F is lower where development is *higher* (inverse correlation) a pattern we have referred to above as "pre-resilience". While we do not have sufficient local data to formally test this hypothesis, this early transition pattern likely reflects a "lag" in the decline of maternal mortality in poorer parts of newly transitioning countries.

3. Shortly after the onset of SDIM transition, a pattern of "female resilience" emerges in which the survival advantage of women is greatest in cross-section in places where SES or development is least.

In every situation we have examined, a striking and not immediately intuitive pattern emerges in cross-section soon after onset of transition: M/F becomes *positively* correlated with indices of development. This happens because as we move our attention from regions with high indices of development to regions with low indices of development we observe that both men and women tend to have lower survival rates, but men decrease more rapidly than women (i.e., M/F tends to be lower for less well-off regions). This "female resilience" pattern between indices of SES and M/F appears subsequently to persist.

This "resilience" pattern emerges within a couple of decades after the residual effects of maternal mortality as a female cause of death dissipates, as it did in the period 1900-1940 in the most developed countries, perhaps around 1990 for the Group 2 countries, and is just beginning to emerge in the last decade in Group 3 countries. That this relationship emerges so predictably as epidemiologic transition progresses—in more or less every observable culture and society (except those poorest of the Group 3 countries and the Group 4 countries which have not yet entered transition)—suggests that the pattern is unlikely to be explained by any specific policy, custom, habit, medical treatment, or health behavior which vary idiosyncratically over time and place.

4. M/F continues to decline even after the immediate contribution of declines in maternal mortality is accounted for.

What might not, *ex ante*, have seemed inevitable is observed: a decade or two after the impact of maternal mortality has largely dissipated—e.g. developed countries after 1950 or Group 2 countries after 1980—M/F *continues* to decline for some further decades. We have not explored in this paper the reasons for this continued decline nor the best explanations for the timing of the turnabout described in the next point, but note here the universality of the pattern among Group 1 counties—including Japan, which may in other regards prove an outlier—and the evidence that Group 2 countries are following the same pathway.

5. At a certain point later in transition, the longitudinal pattern of declining M/F turns around—M/F rises as "men start to catch up". This inflection point in the SDIM transition is evident in almost all high-income (Group 1) countries, as well as most middle-income (Group 2) countries.

Best observed presently for the most advanced (Group 1) countries (Figure 8), with a strong signal that Group 2 is poised to follow, a further change in SDIM appears to occur: men are catching up, with M/F slowly rising in the US since about 1970 and in the rest of the developed world (Groups 1 and 1E) between that time and 1990, while improvement in the survival of men appears to have begun in Group 2 countries between 2000 and the present. It is instructive to investigate the pattern within Japan, one of the world's fastest developing countries after World War II and with a distinctive set of cultural norms. As seen in Figure 11, growth in per capita income was remarkable, and with growth came greater disparities among the regions of the country in terms of mean per capita income. The evolution of the resilience pattern is also evident, with a hint that some prefectures are "slipping" towards lower M/F, consistent with the less marked "U" shape longitudinal pattern in Japan compared with that seen in other Group 1 countries in Figure 4.

6. Over time, the female resilience pattern—the positive association of M/F with SES—strengthens.

Whether comparing within groups of countries or regions within a single country, there is compelling evidence that the resilience pattern, in which women survive relatively better in circumstances of lesser advantage, strengthens over time, with the correlation (Spearman's Rho) between M/F and several measures of SES eventually reaching the range of 0.8 or higher. Noteworthy is the perpetuation of this resilience pattern after the tipping point where male survival improves relatively (approximately 1970 for Group 1 and 2000 or so for Group 2).

7. It would appear that the patterns of SDIM observed through the epidemiologic transition for high-income (Group 1) countries are being recapitulated in low- and middle-income countries (Groups 2 and 3).

Our observations may offer a new way of looking at the epidemiologic transition stages as originally defined in 1971 (Omran 1971; Fink 2013). Omran was writing, as chance would have it, at a critical historic moment that he could not have foreseen, as Group 1 countries were moving from the era of ever-improving relative survival for women into the modern era in which men have begun to catch up. At that very time, those countries we now dub Group 2 were beginning to enter transition. Omran defined the “quartet” now generally appreciated to be the cornerstones of epidemiologic transition: 1) *decline in fertility rates* with a concomitant decline in maternal mortality; 2) *rise in labor wages and productivity*, with associated social welfare benefits including better nutrition and housing; 3) *decline in malnutrition and infections as the major causes of death, with emergence of chronic diseases* as has been seen in Group 1 and now evident in Groups 2 and 3 as well; and 4) despite the emergence of non-communicable chronic diseases, *a dramatic rise in overall LE* due to dramatic reductions in infant mortality and acute infections.

Based on our own observations, we would add to Omran’s list a fifth phenomenon: the emergence of the female survival advantage, characterized here as “resilience” from the emerging NCD epidemic. Moreover, we would speculate that the cresting of that advantage as development proceeds, now evident in all developed countries, may demarcate yet a further phase in the demographic transition, though it is too early to do more than prognosticate, as Group 2 countries as a group have just entered this phase, and Group 3 countries have yet to arrive.

Perhaps more importantly, from the perspective of SDIM, transition appears to demonstrate an impressively consistent pattern, at least based upon the data available. Viewing Figure 8 through the lens of what was learned from examination of earlier decades for Group 1, one could readily imagine that the x-axis represents not 4 decade-markers for each of four groups of nations, but 16 “place-time” markers, structured like a classical “rondo” in which each group embarks on the transition pathway 30-40 years after the previous one, then replicates its path. Obviously it is premature to consider this empirically proved, but we offer a prediction which can be verified in the future.

8. *In wealthy countries, and wealthiest regions within such countries, M/F approaches—but does not reach—unity.*

From the evidence presented it is clear that some Group 1 countries as a whole, e.g. Iceland,

and within highly developed nations some states or counties, such as Santa Clara California[1], have M/F ratios that are approaching 0.96 or 0.97 for LE and 0.95 for S70. We use the term "approach" with great intention, as we not only can observe these high values but also the slow assent which preceded, demarcating these settings from others—earlier in time or in poorer countries—in which identical M/F numerical values would garner an altogether different interpretation.

It is equally noteworthy that we observe no cases of M/F>1 as would be expected if these near-unity values represented "mean" levels around which there was random variation. In point of fact a value in excess of 1 is not encountered in a single country or sub-region of a Group 1 country, nor even in a Group 2 country (except perhaps a handful of Chinese counties, mostly rural in a unique setting for which there are other plausible explanations related to family planning policies, son preference, and their unintended social consequences). This would suggest that M/F_{LE} =0.97 represents an upper bound, at least barring any major change in causes of mortality that might impact the sexes differentially.

9. Risky behaviors, such as smoking or alcohol consumption, have been identified in some settings as causal or contributory to the observed variation in SDIM. However, the consistency of the pattern in different countries and cultures suggests more "upstream" determinants driving the disproportionate gains in female survival over time and the strong ubiquitous "resilience" pattern that has emerged.

What factors underlie this phenomenon? As noted it is unlikely that maternal mortality, or other adverse health impacts associated with reproduction, play a role—even lingering—in this phenomenon that seems very robust to variation in geography, culture and ethnicity. It might be tempting to attribute this phase to the more rapid adoption by men than women of particular subsets of "bad behavior"—tobacco and alcohol abuse, dangerous use of motor vehicles, violence, or work in dangerous occupations, to name the more obvious contenders—or that the advantage relates to women's known greater propensity to use the health care system (Bertakis et al. 2000; Sindelar 1982; Oksuzyan et al. 2008); indeed, there is substantial evidence that each of these is a proximate cause of differential mortality between men and women in some

[1] From which we write.

settings (Concha-Barrientos et al. 2004; Cutler et al. 2011; Ezzati et al. 2008; Hunter and Reddy 2013; Kalben 2002; McCartney et al. 2011; Norström and Razvodovsky 2010; Tomkins et al. 2012). The ubiquity of the pattern globally, after adjusting for stage of development—despite differences in sex-specific behaviors in different regions, cultures and societies[2]—suggests that the resilience of women to socio-economic adversity during the "post-maternal mortality" era development—or conversely the vulnerability of men not evident when women still died frequently in childbirth-- may have a more fundamental "upstream" origin.

10. The convergence of M/F towards 1 in advanced societies appears to be associated with convergence of the lifestyles of men and women.

It might be tempting to explain the "inflection point" in SDIM by one or another social/behavioral changes that occurred in this time frame— for example, in some countries women began to smoke more, joined traditionally male sectors of the workforce, or the like. One parsimonious theory is that with further development, the "least developed" parts of the country, where female resilience is most evident, converge to the higher level of development in other parts of the country. Furthermore, populations migrate towards the economically developed parts of each country where M/F is higher, as particularly evident in rapid urbanization of most developing countries (Fink 2013).

Another way to conceptualize the phenomenon of convergence of M/F towards 1 is to consider broadly the lifestyles emerging in the richest parts of the developed world. On the one hand, women are achieving greater role parity, as legal and social barriers to their advancement are eroding in formerly male-dominated arenas such as construction, manufacturing, business management, academics, other professions, and political leadership. At the same time men, now more often in marital or other relationships in which women share many of the same needs and interests as their own, are more likely in most cultures to provide child-care and

[2] For example, Jiaying Zhao's analysis of mortality data in East Asia from the 1970s reveals that changes in smoking patterns are unlikely to explain the dramatic changes in cause-specific SDIM there (to oversimplify, largely because women never smoked and men always have in societies like China, Japan, and Korea) (Zhao 2013).

other family roles formerly delegated to women. Moreover an increasing fraction of households have single or same-sex heads.

However these cultural phenomena are perceived, there can be little doubt that the formerly distinct sex roles are themselves converging in such societies; viewing this convergence as related to the near convergence of M/F seems inescapable. Japan, which uniquely among Group 1 countries M/F is receding from 1 over the past several decades (see Figure 4), may be instructive, with a very low "Economic Gender Equality Score" component of the 2010 "Gender Equity Index" (Hausmann and Tyson 2010). This notion is supported for US counties by the regression presented in Table 1 (Model 2, Full) in which the occupational similarity index remains a significant correlate of M/F_{70} even when controlling for all the other predictors, as was seen graphically in panel D of Figure 2. Like the Group 1 country comparison, the US also has its "outlier": Alaska. Despite being in the top 10 percent of US states by SES measures, the State has a low occupational similarity index and a far lower-than-expected M/F_{70} as seen in Table 2. Arguably, the regional impact on M/F_{70} noted previously for the US South, even after adjustment for occupational similarity (Table 1), may be a signal supporting a similar mechanism. All, of course, are speculation.

Caveats

There are important limitations to our approach that must be considered:

1. First, as we conceded at the outset, our effort has required use of very diverse data sets, each with quirks and opportunities for imprecision and bias. In many cases we have relied on life table analyses of others to impute sex-specific S_{70} or LE. Perhaps most significantly, we have been limited to what was available; in many cases data do not extend back in time far enough nor geographically widely enough for our purposes, leaving multiple empiric gaps (such as lack of evidence on Group 2 countries when M/F exceeded 1).

2. We do not address over time and place the roles of sex-specific causes of death, with the exception of maternal mortality, and even for that we lack detailed data for most times and countries. Assuming that after epidemiologic transition cardiovascular disease (CVD,

including heart attack, stroke, heart failure) is the major cause of mortality and of its change (Crimmins 1981), as well as a disease that disproportionately kills men, it is tempting to explain all of the late changes in M/F by sex-differences in CVD risk factors: smoking, diet, physical inactivity, etc. Indeed, the positive correlation between M/F and SES has strengthened during the period CVD evolved from a disease of the relatively affluent to a disease largely afflicting poorer populations in Group 1 countries, a pattern evidently recurring in LMICs (Harper et al. 2011; Saquib et al. 2012). Nothing in our analysis can, in and of itself, disprove such a reductionist assertion. However, as noted, any theory of SDIM must be able to account for observations from myriad countries, cultures and ethnicities in which the distributions of many risks, and their timing in relationship to other developmental and medical changes, are variable. For example, there is compelling evidence that in south Asian countries women, more than men, are afflicted by inactivity, poor diet and obesity, even if they smoke far less (Saquib et al. 2012; Saquib et al 2013). The limited availability and quality of disease-specific mortality data has precluded our further exploration of such considerations.

3. We lack data for numerous independent covariates of *a priori* interest—e.g. differential educational attainment and career experience, differences in opportunity for managerial and professional roles, religious laws and customs, differential access to, and quality of, health care, etc. The importance of such unmeasured covariates in our analyses awaits further research.

4. We have no way to account for yet another compelling difference well documented in many societies, namely differential health seeking behavior; women utilize approximately double the healthcare services of their male counterparts in developed societies (Bertakis et al. 2000; Oksuzyan et al. 2008; Sindelar 1982). The importance of this difference as a cause rather than a result of SDIM, outside the context of improvements in obstetric care, is impossible to assess from our data.

5. Even for those covariates that we have investigated—per capita GDP, educational attainment, percent in poverty—we lack consistent definitions and metrics over time.

Implications for pathways mediating SDIM

We return in closing to the question with which we started: why do women live longer than men? Our study aims to better understand the underlying basis of the century-long female survival advantage in current high-income countries, and the emerging advantage in most of the rest of the world.

As noted in the introduction, there are three broad theories that have received attention; we now return to each. The first theory is that women enjoy a hard-wired, *biologic* advantage, conferred during human evolution. While none of the data point to a specific basis, there almost certainly *is* a biologic advantage that seems impervious to—indeed, becomes more evident under—environmental or social stress. How else could we explain the universality of the female survival advantage over time, culture, religion, political regime and place, once the scourge of maternal mortality has been overcome? In not one single US county, nor in any single country in Groups 1-3 including 1E, do more men survive to age 70 than women do.

But despite the data limitations, we can infer more. For while some sex-specific difference in either S_{70} or LE appears to be constant, the magnitude is not. We have seen, with the benefit of longitudinal and cross-sectional observations, that M/F_{LE} is asymptotically approaching 0.97 and M/F_{70} is approaching 0.95, which translates to 2-3 years of extra life on average for women, or a 5 percent higher likelihood of survival to age 70.

So if the life expectancy difference in the Group 1-3 and 1E countries averages 6-8 years currently, and the difference in survival to 70 still exceeds 10 percent in many Group 1 countries, including the US, what accounts for the remainder? The second broad theory proposes that sex-differences in health behaviors deserve consideration. This theory has indeed received a great deal of attention, with special attention to tobacco and alcohol (Bhattacharya et al. 2012; McCartney et al. 2011; Preston and Wang 2011). Differences between the sexes in their proclivities toward violence, dangerous occupations, risky driving, and athletic behaviors no doubt play a role, especially in mortality differences among young adults. But two thorny questions cannot be readily dismissed. First is the need to explain the universality of the pattern of female resilience to social adversity, which appears to be as true of countries like Russia and

Japan as in western Judeo-Christian ones, and is evident in rapidly developing countries like Brazil, China, Iran and Thailand.

Accepting that in almost all societies there are striking and lethal differences between male and female behavior choices, the question remains as to why the different life choices arise, and why even in the face of such choices women still seem to fare better, at least regarding mortality. Here we come to the third broad area of speculation—*socio-biologic differences* between the sexes, which has come to mean hereditary biologic differences whose expression is not manifest in "biology" but in social behavior. Most notable among these behaviors are "nesting" and family-protecting roles, in which sex differences appear common throughout human society and also in other primates—indeed, observed among other animal kingdoms as well. As such one would distinguish the roles of sex hormones as mediators of pathologic changes in blood vessels from their contribution to the social planning and networking behaviors of women, which differ so markedly from men's, at least historically. How, mechanistically, inborn differences in proclivities to behave certain ways may contribute to the resilience of women to social adversity we observe in every culture once epidemiologic transition takes hold is of course is something about which we can only speculate. But in theory, while men may be deprived of the biologic drivers, the protective behaviors themselves could be taught or culturally programmed.

In looking for explanations for the narrowing of male-female differentials in mortality in high income countries, we can reject, for the present, females encountering a biological ceiling. Female survival continues to improve, even in countries with a high level of life expectancy. A more promising line of inquiry, but one we did not pursue because accurate data are not available for many of the countries and time periods covered in this paper, is the influence of differences in health behaviors, advances in medical care, and changes in causes of death. The decline in relative importance of cardiovascular mortality consequent to treatment for hypertension and hyperlipidemia stands out, along with widespread use of aspirin and interventional cardiology. Looking to the future, the prospects for further decreases in male-female differences in survival look good. To the extent that remaining differences are attributable to sex differences in roles and behaviors, a period of "gender homogenization" in which roles and behaviors of men and women converge should result in further convergence of mortality. Finally, consider the most robust finding of this paper: that the largest male-female differences in mortality occur in conditions of socioeconomic adversity. If social welfare programs and economic policy reduce the number of households and communities living in such adverse conditions, the sex-differential for the country as a whole should decrease. We may be entering an era in which only the (modest) female genetic advantage should prevent men from achieving survival parity.

Bibliography

Bertakis, K. D., Azari, R., Helms, J. L., Callahan, E. J., & Robbins, J. A. (2000). Gender differences in the utilization of health care services. *The Journal of Family Practice*, *49*(02), 147–152. http://www.jfponline.com/index.php?id=22143&txttnews[ttnews]=168476

Bhattacharya, B. Y. J., Gathmann, C., & Miller, G. (2012). *The Gorbachev Anti-Alcohol Campaign and Russia's Mortality Crisis* (No. 18589) (pp. 1–45).

Braveman, P., Egerter, S., & Williams, D. R. (2011). The social determinants of health: coming of age. *Annual Review of Public Health*, *32*, 381–98. doi:10.1146/annurev-publhealth-031210-101218

Cai, Y. (2005). *National, Provincial, Prefectural and County Life Tables for China Based on the 2000 Census* (No. 05-03) (pp. 1–20). Seattle, WA.

Cai, Y. (2009). Regional Inequality in China: Mortality and Health. In D. Davis & W. Feng (Eds.), *Creating Wealth and Poverty in Post-Socialist China* (1st ed., pp. 143–155). Stanford, CA: Stanford University Press.

Case, A., & Paxson, C. H. (2005). Sex Differences in Morbidity and Mortality. *Demography*, *42*(2), 189–214. doi:10.1353/dem.2005.0011

Catalano, R., & Bruckner, T. (2006). Secondary sex ratios and male lifespan: Damaged or culled cohorts. *Proceedings of the National Academy of Sciences*, *103*(5), 1639–1643.

Chu, C. Y. C., & Lee, R. D. (2012). Sexual dimorphism and sexual selection: a unified economic analysis. *Theoretical Population Biology*, *82*(4), 355–63. doi:10.1016/j.tpb.2012.06.002

Concha-Barrientos, M., Nelson, D. I., Driscoll, T., Steenland, N. K., Punnett, L., Fingerhut, M. A., et al. (2004). Selected occupational risk factors. In M. Ezzati (Ed.), *Comparative Quantification of Health Risks, Vol.1: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors* (1st ed., pp. 1651–1802). World Health Organization.

Cook, M. B., McGlynn, K. a, Devesa, S. S., Freedman, N. D., & Anderson, W. F. (2011). Sex disparities in cancer mortality and survival. *Cancer Epidemiology* 20(8):1629-37.

Crimmins, E. M. (1981). The changing pattern of American mortality decline, 1940-77, and its implications for the future. *Population and Development Review*, 229-254.

Cullen, M.R.Cummins, C., & Fuchs, V. R. (2012). Geographic and racial variation in premature mortality in the U.S.: analyzing the disparities. *PloS One*, *7*(4), e32930. doi:10.1371/journal.pone.0032930

Cutler, D. M., Lange, F., Meara, E., Richards-Shubik, S., & Ruhm, C. J. (2011). Rising educational gradients in mortality: the role of behavioral risk factors. *Journal of Health Economics*, *30*(6), 1174–87. doi:10.1016/j.jhealeco.2011.06.009

Drevenstedt, G. L., Crimmins, E. M., Vasunilashorn, S., & Finch, C. E. (2008). The rise and fall of excess male infant mortality. *Proceedings of the National Academy of Sciences*, *105*(13), 5016–21. doi:10.1073/pnas.0800221105

Ezzati, M., Friedman, A. B., Kulkarni, S. C., & Murray, C. J. L. (2008). The reversal of fortunes: trends in county mortality and cross-county mortality disparities in the United States. *PLoS Medicine*, *5*(4), e66. doi:10.1371/journal.pmed.0050066

Fink, G. (2013). *Urbanization and child mortality – Evidence from the demographic and health surveys* (pp. 1–22). http://globalhealth2035.org/sites/default/files/working-papers/urbanization-and-child-mortality.pdf

Gabel, C. L., & Gerberich, S. G. (2002). Risk factors for injury among veterinarians. *Epidemiology*, *13*(1), 80–6. http://www.ncbi.nlm.nih.gov/pubmed/11805590

Gerry, C. J. (2012). The journals are full of great studies but can we believe the statistics? Revisiting the mass privatisation - mortality debate. *Social Science & Medicine*, *75*(1), 14–22. doi:10.1016/j.socscimed.2011.12.027

Gillespie, D. O. S., Trotter, M. V., & Tuljapurkar, S. D. (2014). Divergence in age patterns of mortality change drives international divergence in lifespan inequality. *Demography*, *51*, 1003–1017. doi:10.1007/s13524-014-0287-8

Gorman, B. K., & Read, J. G. (2007). Why Men Die Younger than Women. *Geriatrics and Aging*, *10*(3), 179–181.

Harper, S., Lynch, J., & Smith, G. D. (2011). Social determinants and the decline of cardiovascular diseases: understanding the links. *Annual Review of Public Health*, *32*, 39–69. doi:10.1146/annurev-publhealth-031210-101234

Hausmann, R., & Tyson, L. D. (2010). *Global Gender Gap Report* (pp. 1–334). Geneva, Switzerland: World Economic Forum.

Helweg-Larsen, K., & Juel, K. (2000). Sex differences in mortality in Denmark during half a century, 1943-92. *Scandinavian Journal of Public Health*, *28*(3), 214–221. doi:10.1177/14034948000280031101

Hogan, M. C., Foreman, K. J., Naghavi, M., Ahn, S. Y., Wang, M., Makela, S. M., et al. (2010). Maternal mortality for 181 countries, 1980–2008: a systematic analysis of progress towards Millennium Development Goal 5. *The Lancet*, *375*(9726), 1609 – 1623. doi:10.1016/S0140-6736(10)60518-1Cite

Horton, R., & Lo, S. (2013). Investing in health: why, what, and three reflections. *Lancet*, *382*(9908), 1859–61. doi:10.1016/S0140-6736(13)62330-2

Hunter, D. J., & Reddy, K. S. (2013). Noncommunicable diseases. *The New England Journal of Medicine*, *369*(14), 1336–43. doi:10.1056/NEJMra1109345

Kalben, B. B. (2002). Why men die younger: Causes of mortality differences by sex. *North American Actuarial Journal*, *4*(4), 83–111.

Kornai, J. (1994). Transformational recession: The main causes. *Journal of Comparative Economics*, *19*, 39–63.

Kruger, D. J., & Nesse, R. M. (2004). Sexual selection and the Male : Female Mortality Ratio. *Evoloutionary Psychology*, *2*, 66–85.

Lozano, R., Naghavi, M., Foreman, K., Lim, S., Shibuya, K., Aboyans, V., et al. (2012, December 15). Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. doi:10.1016/S0140-6736(12)61728-0

MacIntyre, S., Hung, K., & Sweeting, H. (1996). Gender differences in health: Are things really as simple as they seem? *Social Science & Medicine*, *42*(4), 617–624.

Mage, D. T., & Donner, M. (2006). Female resistance to hypoxia: Does it explain the sex difference in mortality rates? *Journal of Women's Health*, *15*(6), 786–794.

McCartney, G., Mahmood, L., Leyland, A. H., Batty, G. D., & Hunt, K. (2011). Contribution of smoking-related and alcohol-related deaths to the gender gap in mortality: evidence from 30 European countries. *Tobacco Control*, *20*(2), 166–8. doi:10.1136/tc.2010.037929

Mckee, M., & Shkolnikov, V. (2001). Understanding the toll of premature death among men in eastern Europe. *British Medical Journal*, *323*(November), 1051–1055.
Møller, A. P., Fincher, C. L., & Thornhill, R. (2009). Why men have shorter lives than women: effects of resource availability, infectious disease, and senescence.

American Journal of Human Biology, *21*(3), 357–64. doi:10.1002/ajhb.20879
Mooney, G. (2002). Shifting sex differentials in mortality during urban epidemiological transition: the case of Victorian London. International Journal of Population Geography, 8(1), 17–47. doi:10.1002/ijpg.233 38
Murphy, M., Bobak, M., Nicholson, A., Rose, R., & Marmot, M. (2006). The widening gap in mortality by educational level in the Russian Federation, 1980-2001. *American Journal of Public Health*, *96*(7), 1293–9. doi:10.2105/AJPH.2004.056929

Ng, M., Freeman, M. K., Fleming, T. D., Robinson, M., Dwyer-Lindgren, L., Thomson, B., et al. (2014). Smoking prevalence and cigarette consumption in 187 countries, 1980-2012. *Journal of the American Medical Association*, *311*(2), 183–92. doi:10.1001/jama.2013.284692

Norström, T., & Razvodovsky, Y. (2010). Per capita alcohol consumption and alcohol-related harm in Belarus, 1970-2005. *European Journal of Public Health*, *20*(5), 564–8. doi:10.1093/eurpub/ckq011

Oeppen, J., & W.Vaupel, J. (2002). Broken limits to life expectancy. *Demography*, *296*, 1029–1031.

Oksuzyan, A., Juel, K., Vaupel, J. W., & Christensen, K. (2008). Men: good health and high mortality. Sex differences in health and aging*. *Aging Clinical and Experimental Research*, *20*(2), 25–28.

Omran, A. R. (1971). The epidemiologic transition: a theory of the epidemiology of population change. *The Milbank Memorial Fund Quarterly*, *49*(4), 509–538. doi:10.1111/j.1468-0009.2005.00398.x

Preston, S. H., & Wang, H. (2011). Sex Mortality Differences in the United States: The role of cohort smoking patterns. *Demography*, *43*(4), 631–646.

Rahman, O., Strauss, J., Gertler, P., Ashley, D., & Fox, K. (1994). Gender Differences in Adult Health: An International Comparison. *The Gerontologist*, *34*(4), 463–469. doi:10.1093/geront/34.4.463

Ristvedt, S. L. (2014). The evolution of gender. *JAMA Psychiatry*, *71*(1), 13–14. doi:10.1001/jamapsychiatry.2013.3199.

Saquib, N., Khanam, M. A., Saqib, J., Anand, S., Chertow, G. M., Barry, M., et al. (2013). High prevalence of type 2 diabetes among the urban middle class in Bangladesh. *BMC Public Health*, *13*(1), 1032. doi:10.1186/1471-2458-13-1032

Saquib, N., Saquib, J., Ahmed, T., Khanam, M. A., & Cullen, M. R. (2012). Cardiovascular diseases and type 2 diabetes in Bangladesh: a systematic review and meta-analysis of studies between 1995 and 2010. *BMC Public Health*, *12*(1), 434. doi:10.1186/1471-2458-12-434

Sindelar, J. L. (1982). Differential use of medical care by sex. *The Journal of Political Economy*, *90*(5), 1003–1019.

Taylor, M. D., Whiteman, M. C., Fowkes, G. R., Lee, A. J., Allerhand, M., & Deary, I. J. (2009). Five Factor Model personality traits and all-cause mortality in the Edinburgh Artery Study cohort. *Psychosomatic Medicine*, *71*(6), 631–41. doi:10.1097/PSY.0b013e3181a65298

Tomkins, S., Collier, T., Oralov, A., Saburova, L., McKee, M., Shkolnikov, V., et al. (2012). Hazardous alcohol consumption is a major factor in male premature mortality in a typical Russian city: prospective cohort study 2003-2009. *PloS One*, *7*(2), e30274. doi:10.1371/journal.pone.0030274

Trovato, F., & Lalu, N. M. (2005). A Continuing Pattern of Decline of the Sex Differential in Life Expectancy in Canada: Early 1970s – Late 1990s. In *International Population Conference of the International Union for the Scientific Study of Population (IUSSP)* (pp. 1–61).

Tulchinsky, T. H., & Varavikova, E. A. (1993). Addressing the epidemiologic transition in the former Soviet Union: Strategies for health system and public health reform in Russia. *American Journal of Public Health*, *86*(3), 313–320.

Umberson, D., & Montez, J. K. (2010). Social relationships and health: A flashpoint for health policy. *Journal of Health and Social Behavior*, *51 (Suppl)*, 1–16. doi:10.1177/0022146510383501.Social
Verbrugge, L. M. (2012). The twain meet : Empirical explanations of sex differences in health and mortality. *Journal of Health and Social Behavior*, *30*(3), 282–304.

Vogt, T. C., & Kluge, F. A. (2014). Can public spending reduce mortality disparities? Findings from East Germany after reunification. *The Journal of the Economics of Ageing*, 1–7. doi:10.1016/j.jeoa.2014.09.001 40

Waldron, I. (1983). Sex differences in human mortality: The role of genetic factors. *Social Science & Medicine*, *17*(6), 321–333.

Waldron, I. (1976). Why do women live longer than men? *Social Science & Medicine*, *10*, 349–362.

Wang, H., Dwyer-Lindgren, L., Lofgren, K. T., Rajaratnam, J. K., Marcus, J. R., Levin-Rector, A., et al. (2012). Age-specific and sex-specific mortality in 187 countries, 1970-2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859), 2071–94. doi:10.1016/S0140-6736(12)61719-XCite

Weidner, G., & Cain, V. S. (2003). The gender gap in heart disease: Lessons from Eastern Europe. *American Journal of Public Health*, *93*(5), 2002–2004.

Yang, Y., & Kozloski, M. (2012). Change of sex gaps in total and cause-specific mortality over the life span in the United States. *Annals of Epidemiology*, *22*(2), 94–103. doi:10.1016/j.annepidem.2011.06.006

Zaridze, D., Lewington, S., Boroda, A., Scélo, G., Karpov, R., Lazarev, A., et al. (2014). Alcohol and mortality in Russia: prospective observational study of 151,000 adults. *The Lancet*, *383*(9927), 1465–73. doi:10.1016/S0140-6736(13)62247-3

Zatoński, W. A. (2011). Epidemiological analysis of health situation development in Europe and its causes until 1990. *Annals of Agricultural and Environmental Medicine*, *18*(2), 194–202.

Zhao, J. (2013). *Changing cardiovascular disease mortality and advancing longevity: Hong Kong, Shanghai and Taipei*. Diss. PhD dissertation, The Australian and Demographic and Social Research Institute, The Australian National University, 2013.

Table 1. Regression Table Describing Sex Differences in Survival Across US Counties, 2006-2010

Table cells: *Regression Coefficient / Beta Coefficient*

Predictors	**Outcome: M/F S_{70}**			**Outcome: Male S_{70}**	**Outcome: Female S_{70}**
Predictors	**Univariate (n=3,059)**	**Model 1, Limited (n=3,059)**	**Model 2, Full (n=3,059)**	**Model 3a, Full (n=3,059)**	**Model 3b, Full (n=3,059)**
% Poverty	-0.005 / -0.657***	-0.002 / -0.297***	-0.003 / -0.354***	-0.001 / -0.195***	-0.000 / -0.095**
Log Income PC	0.154 / 0.650***	0.117 / 0.459***	0.059 / 0.323***	0.091 / 0.437***	0.012 / 0.172***
% Lower Edu /<12 Yrs)	-0.003 / -0.541***	-0.001 / -0.119***	-0.000 / -0.088**	0.000 / 0.004	-0.000 / -0.152***
Occupational Similarity Index	0.437 / 0.643***		0.276 / 0.320***	0.202 / 0.270***	0.020 / 0.058*
Male Smoke	-0.002 / -0.251***		0.000 / 0.007	-0.000 / -0.015	
Fem Smoke	-0.003 / -0.279***		-0.001 / -0.012		-0.001 / -0.010
Male Obesity	-0.006 / -0.419***		0.001 / 0.010	-0.000 / -0.012	

Female Obesity	-0.006 / -0.444***		0.000 / 0.022*		-0.000 / -0.070**
R^2		0.628	0.720	0.709	0.548

Inference: *P<0.05, **P<0.01, ***P<0.001

Data from the 2006-2010 NCHS's Compressed Mortality Files and US Census Bureau's 5-Yr 2010 ACS at the county level.

Data restricted to Non-Hispanic Whites in counties with >100 Non-Hispanic White deaths under age 70 between 2006-2010

Table 2: Alaska and Alaskan Counties

I. Alaska

	M/F S70	Predicted M/F S70*	% Poverty	Income per Capita	% Low Education, <12 Yrs School	Occupational Similarity Index
Alaska	0.85	0.92	7.5	51,971	10.0	0.39
Mean, All States	0.90	0.90	13.2	41,948	12.3	0.51

II. Five Largest Counties in Alaska

	M/F S70	Predicted M/F S70*	% Poverty	Income per Capita	% Low Education, <12 Yrs School	Occupational Similarity Index
Matanuska-Susitna Borough, AK	0.80	0.89	7.9	56,634	14.4	0.35
Kenai Peninsula Borough, AK	0.82	0.90	8.6	57,096	12.4	0.37
Fairbanks North Star Borough, AK	0.85	0.93	5.8	58,945	7.1	0.45
Juneau, AK	0.85	0.94	5.2	70,092	6.8	0.62
Anchorage, AK	0.84	0.94	3.6	76,228	7.7	0.64
Mean, All Counties	0.84	0.82	15.2	45,308	20.7	0.56

*Predicted M/F S70 is predicted using % Poverty, Income per Capita, and % Not Graduate High School

Appendix A: Data Sources

For the US analyses of the level of state and county, we obtained S70 data using CDC/NCHS Compressed Mortality Files for the year 2010. Due to the established association between race and mortality in the US (Cullen et al. 2012) we only utilized data for non-Hispanic Whites.

For international intra-country analyses, we used country-specific census records for the latest available year to study SDIM at the region or province level (Cai 2005, 2009). Where S70 was not available, we used LE. We acquired mortality data for Russian oblasts for years 1978, 1988, and 1998, through the population-based HAPIEE (Health, Alcohol, and Psychosocial factors in Eastern Europe) study.

We used the Human Mortality Database (HMD) and to obtain country-level time-series S70 data for developed countries around the world for years 1900-2010. We obtained country-level time-series LE data from the Global Burden of Disease project for all countries for years 1970-2010 (Wang et al. 2012).

Data Sources for Explanatory Variables

Except for limited purposes, we restricted our consideration of possible "explanatory variables" to the handful of measures of socioeconomic status that were 1) widely available for the different comparisons of interest; 2) generally accepted as measures of social and economic development; and 3) reasonably comparable despite differences in definitions within each historic and national context. Using these criteria we identified four metrics: per capita income or GDP; educational attainment; percent living below nationally defined poverty levels; and the Human Development Index, which we modified by excluding the LE component to avoid autocorrelation. These metrics were not chosen because of any strong prior belief in their importance relative to other SES measures and should not be construed as causally linked to the observed patterns of SDIM in different places and times. Additional behavioral data were collected to compare our approach with hypotheses presented previously in the literature, such as the roles of smoking and drinking in specific contexts.

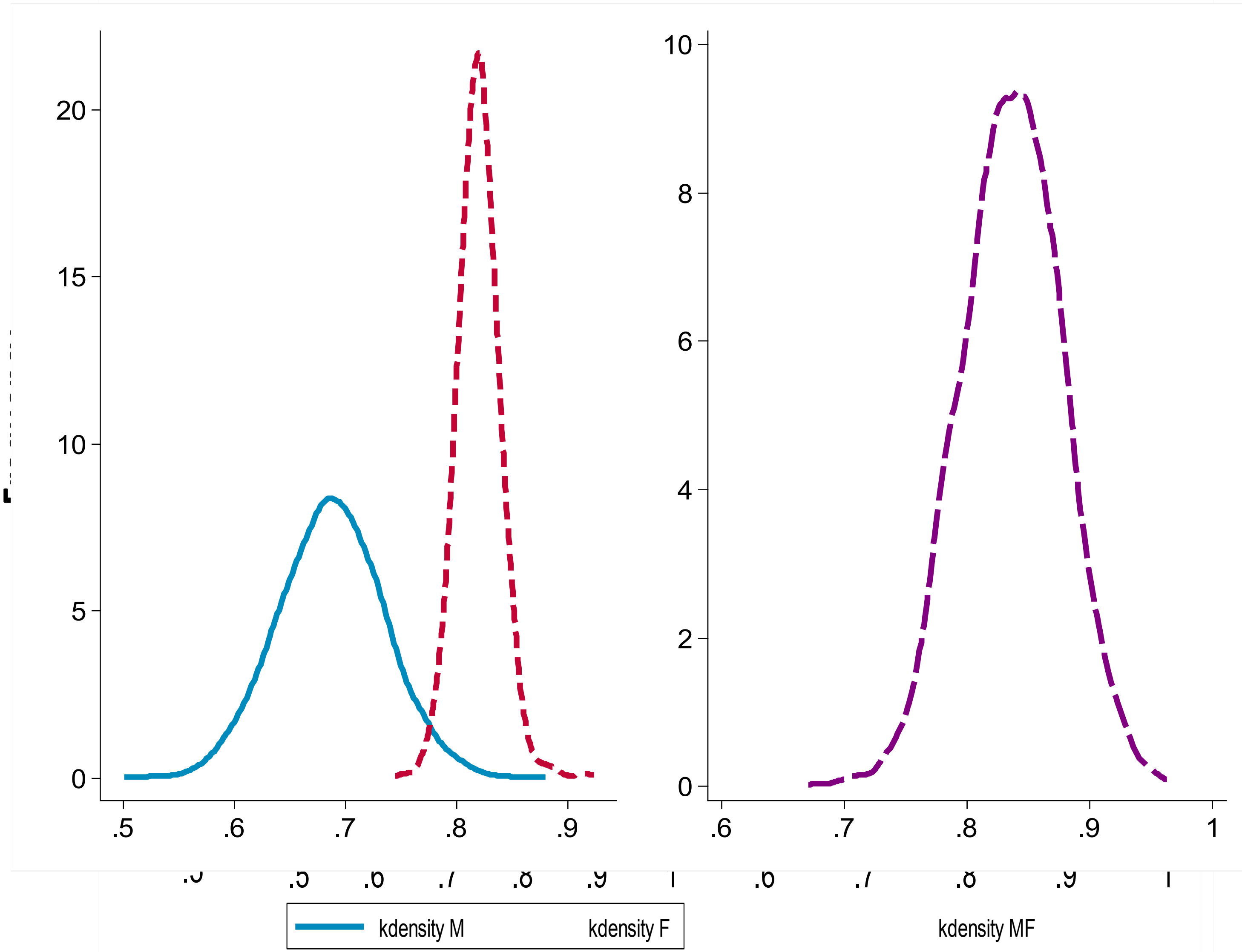
We utilized numerous sources to collect these social, economic, and environmental variables. For the US analyses, we used the 2010 Behavioral Risk Factor Surveillance Surveys (BRFSS) County database to obtain county-level data on obesity, poverty, and smoking rates. We supplemented this with data from the American Community Survey on population size, high school graduation rates, and per capita income. To explore lifestyle convergence in the US, we constructed a county-level occupational similarity index, measuring the difference between the male and female distributions of occupations, treating "not in the labor force" as an occupation. The index is 1 minus the sum of the changes in the male (or female) distribution required to make the sex distributions in a county identical (6).

We used other country-specific censuses to obtain Japanese income data, Sri Lankan education data, and Brazilian poverty data. We obtained data on country-level smoking prevalence for 1980-2010 through a recent study which provided the relevant data in their supplement section (Ng et al. 2014).
Per capita GDP data for 1970-2010 for countries was obtained from the World Bank. In addition to GDP, we collected maternal mortality data for each country for 1970-2008 using data collected to evaluate progress on Millennium Development Goal 5 (Hogan et al. 2010).

All data sources are summarized in Supplemental Table 2.

In each instance where we fit an OLS regression, we weighted by log population, which we obtained through country-specific censuses and the World Bank.

Figure 1: Frequency



3,059 counties with at last 100 deaths/year between 2006-2010

Figure 2 . M_{S70}, F_{S70}, and M/F_{S70} vs Poverty, Log Income, Education, and Occupation

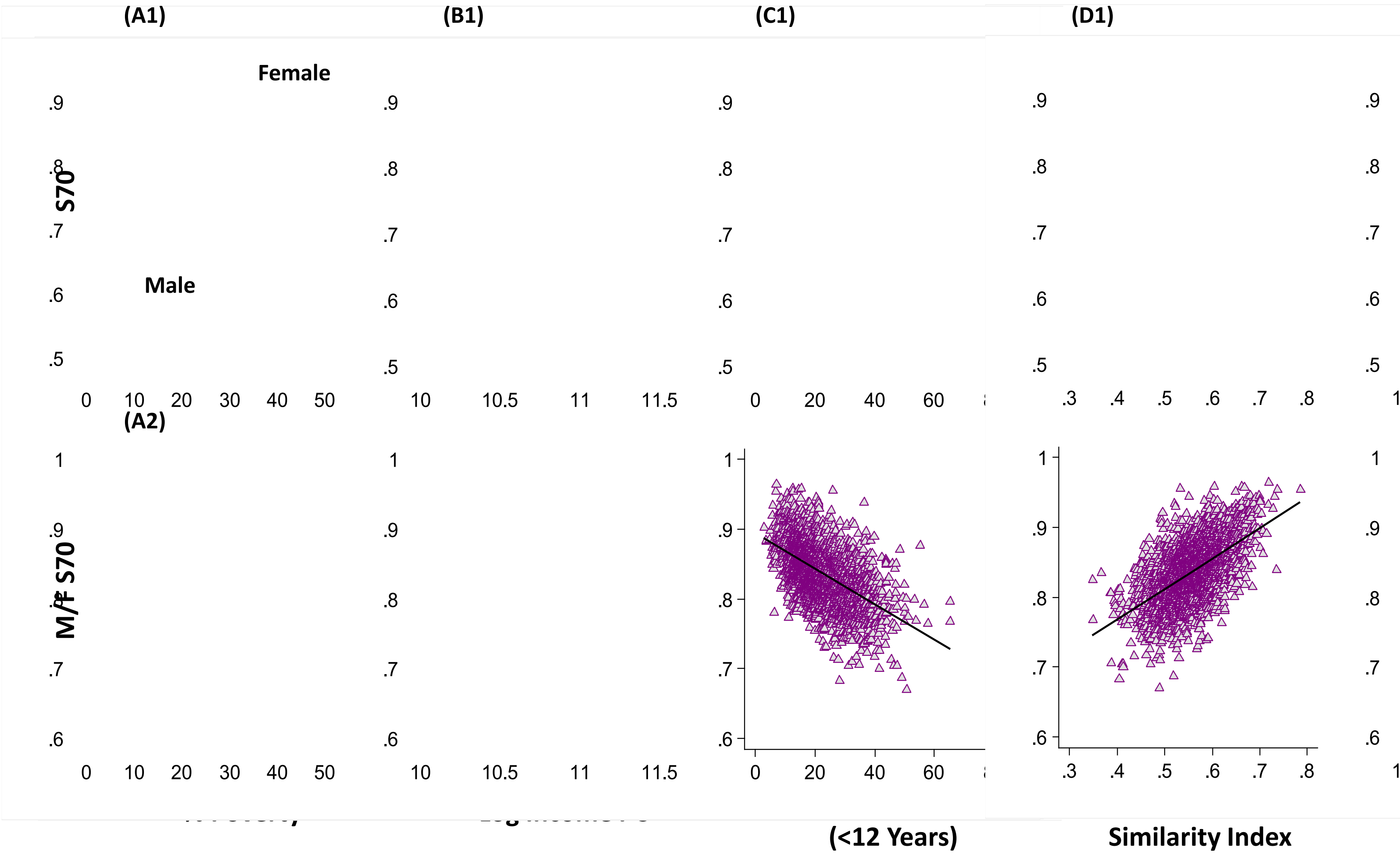
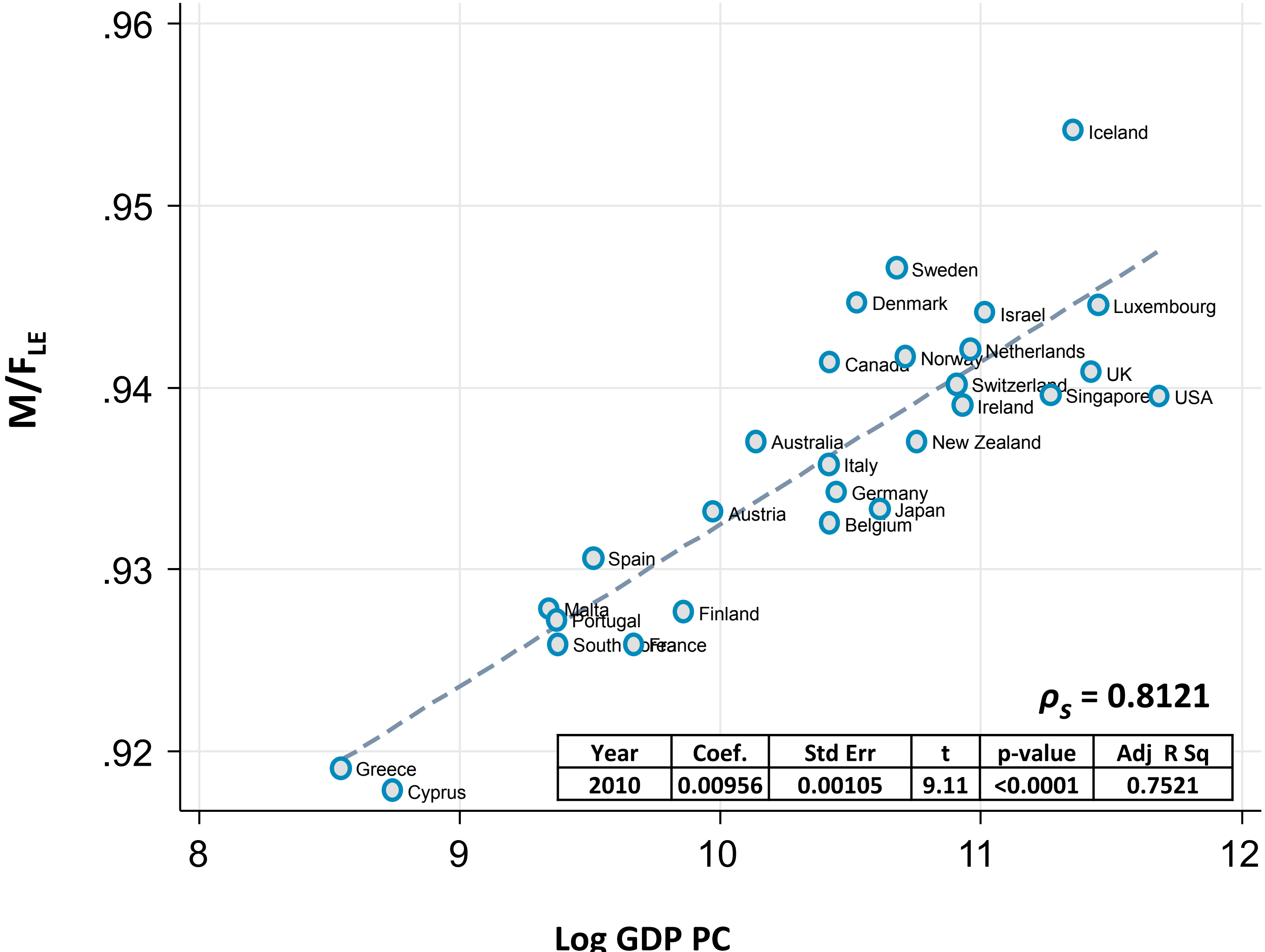


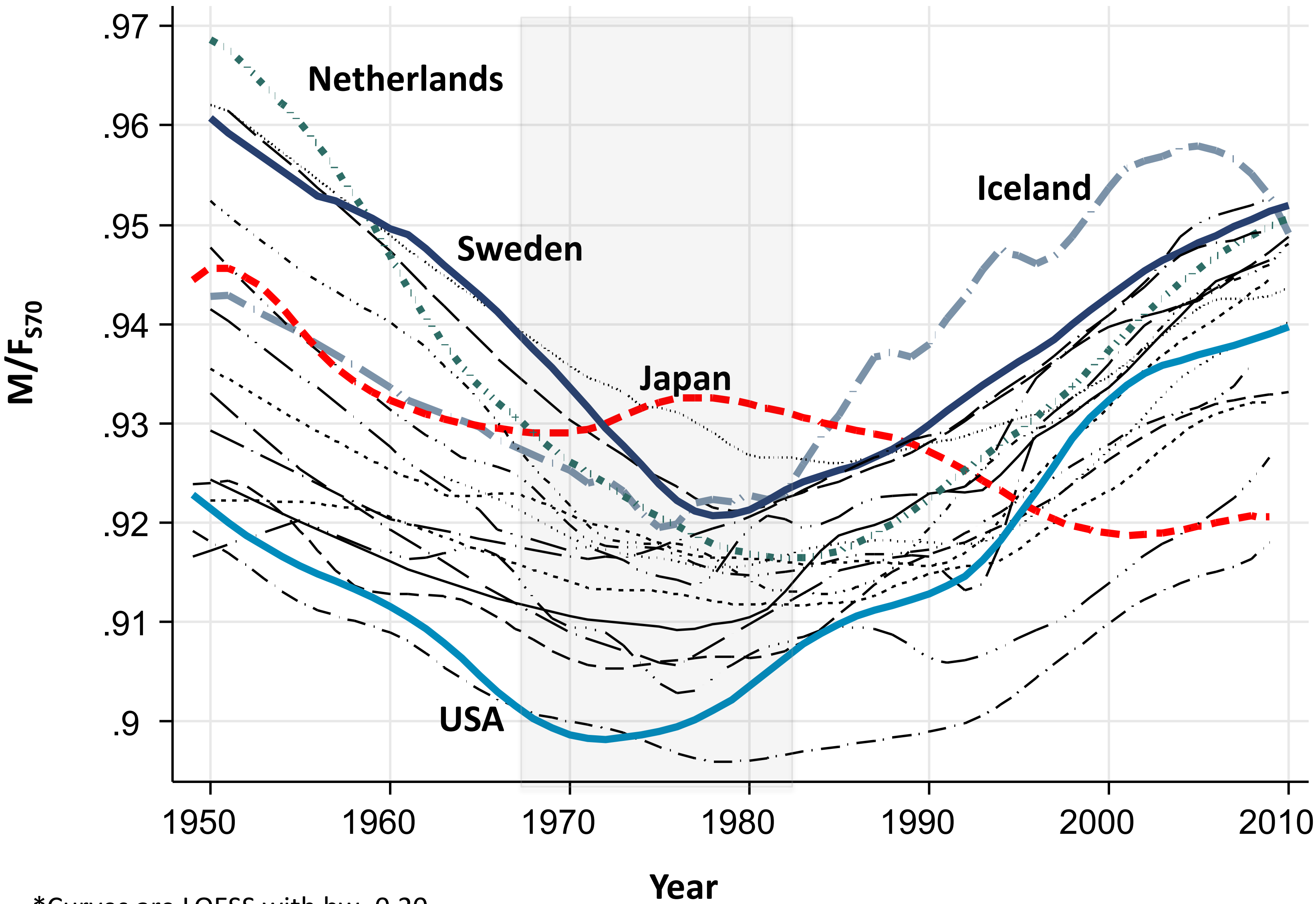
Figure 3: M/F_{LE} v. log per cap GDP for Group 1 countries, 2010



Year	Coef.	Std Err	t	p-value	Adj R Sq
2010	0.00956	0.00105	9.11	<0.0001	0.7521

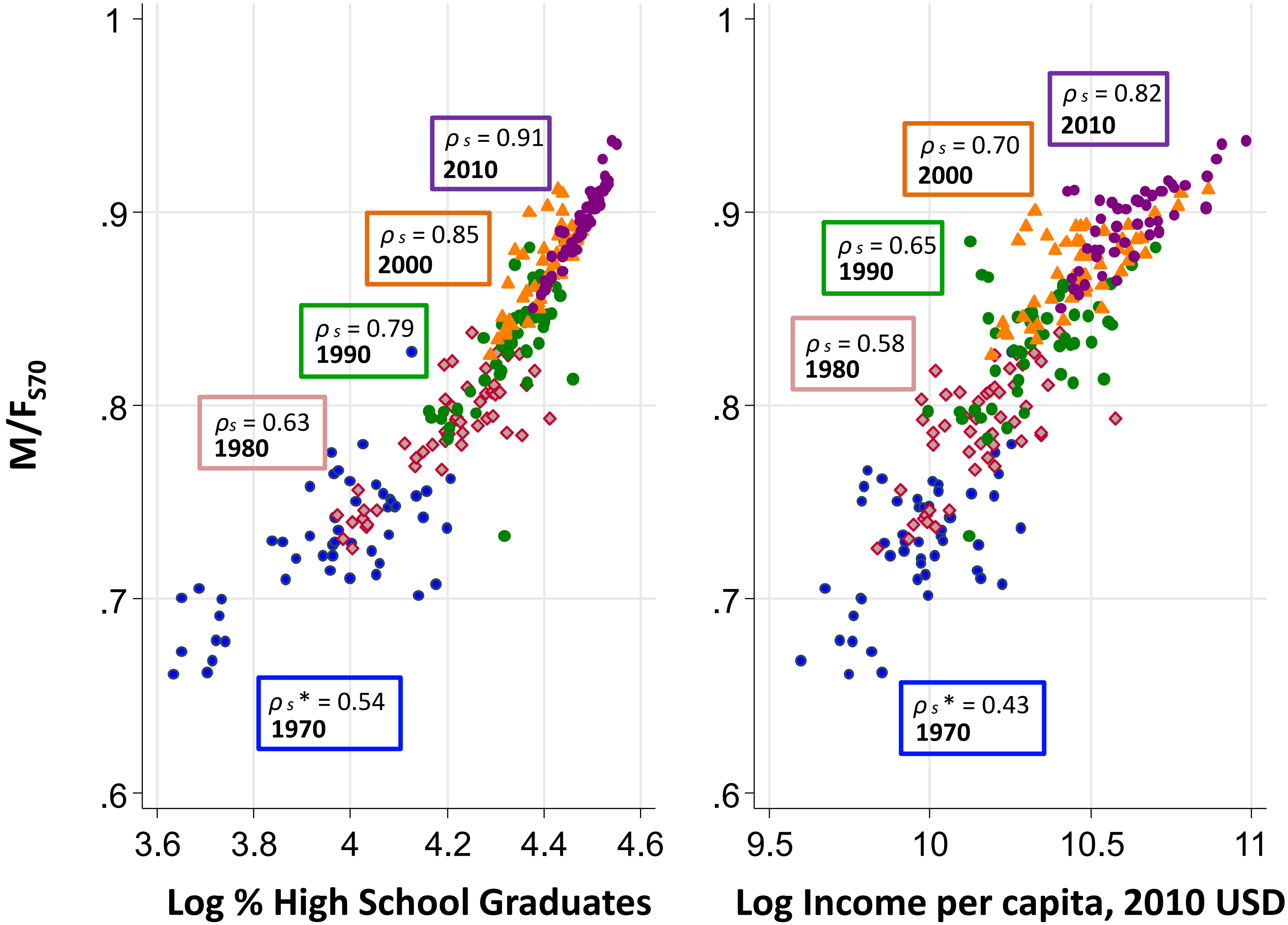
Murray, Lancet

Figure 4: M/F_{S70} over Years 1950-2010, 20 Wealthiest OECD Countries



*Curves are LOESS with bw=0.20

Figure 5: M/F_{S70} vs Average HS Grad Rate and Average Income, by Decade, US States



*Spearman Correlation Coefficients

Figure 6: Male and Female LE and M/FLE over Years for USA (Top Row) and Other Developed Countries (Bottom Row), 1900-2010

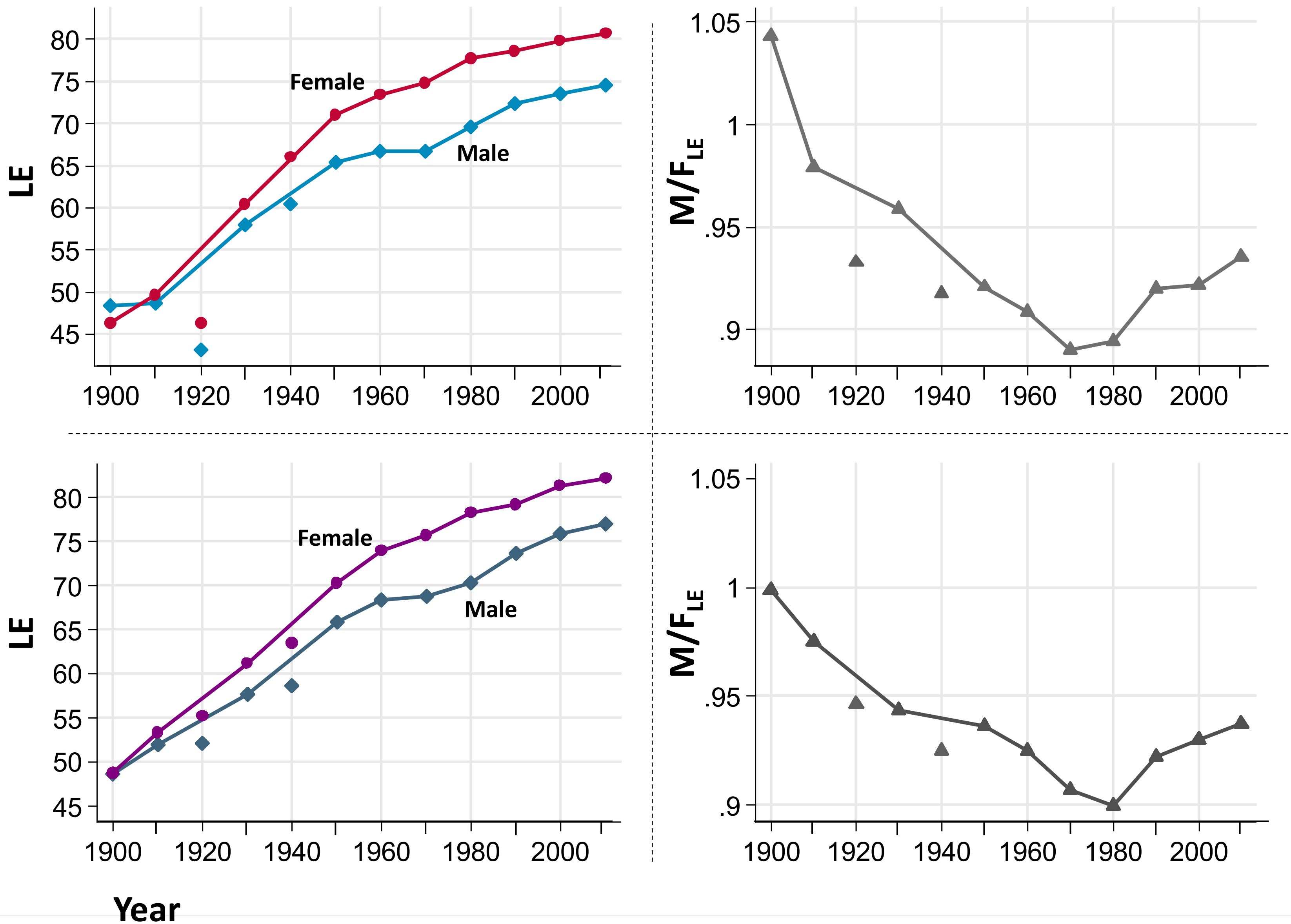


Figure 7: M/F_{LE} vs Average LE for 18 Group 1 Countries, by Decade, 1900-2010

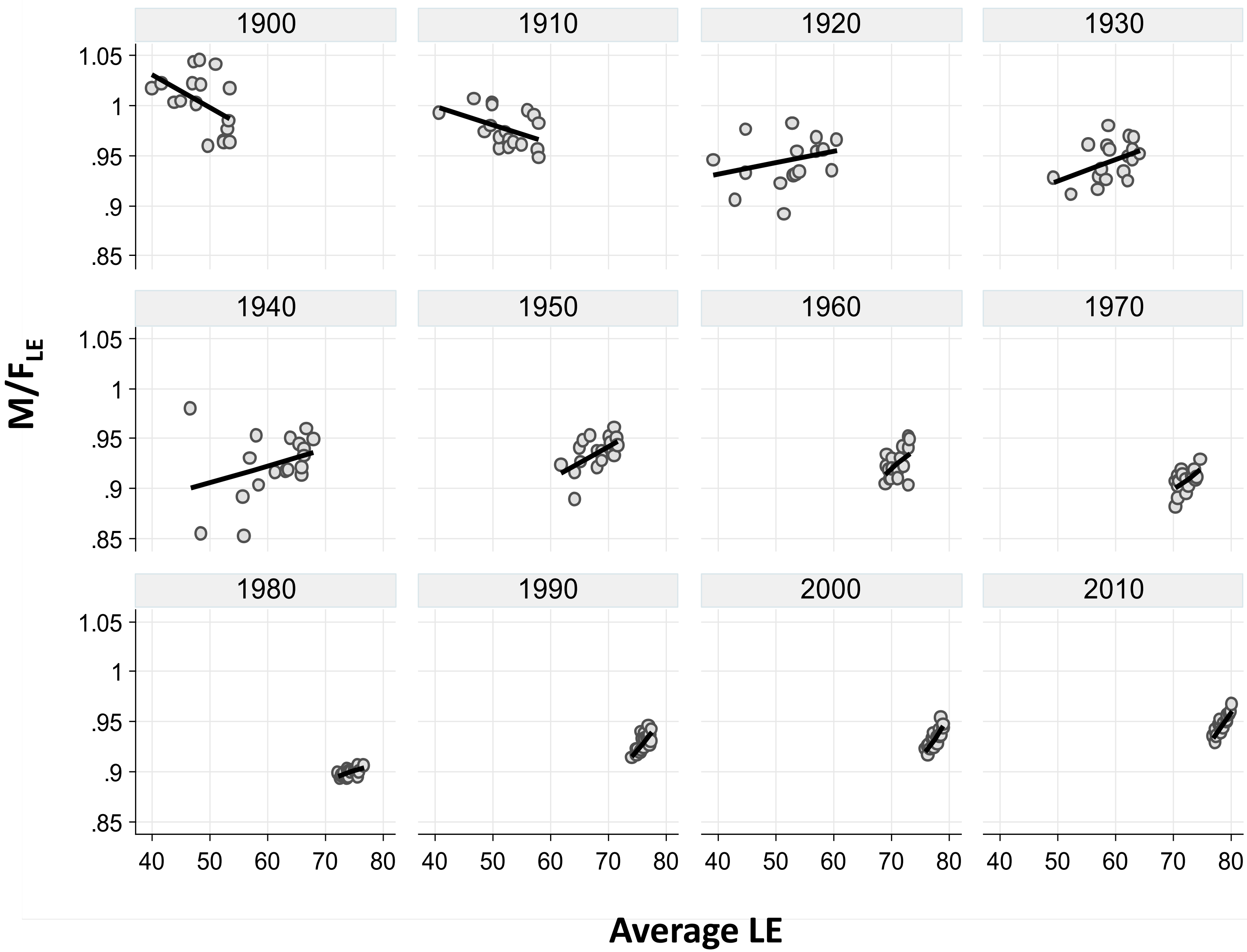
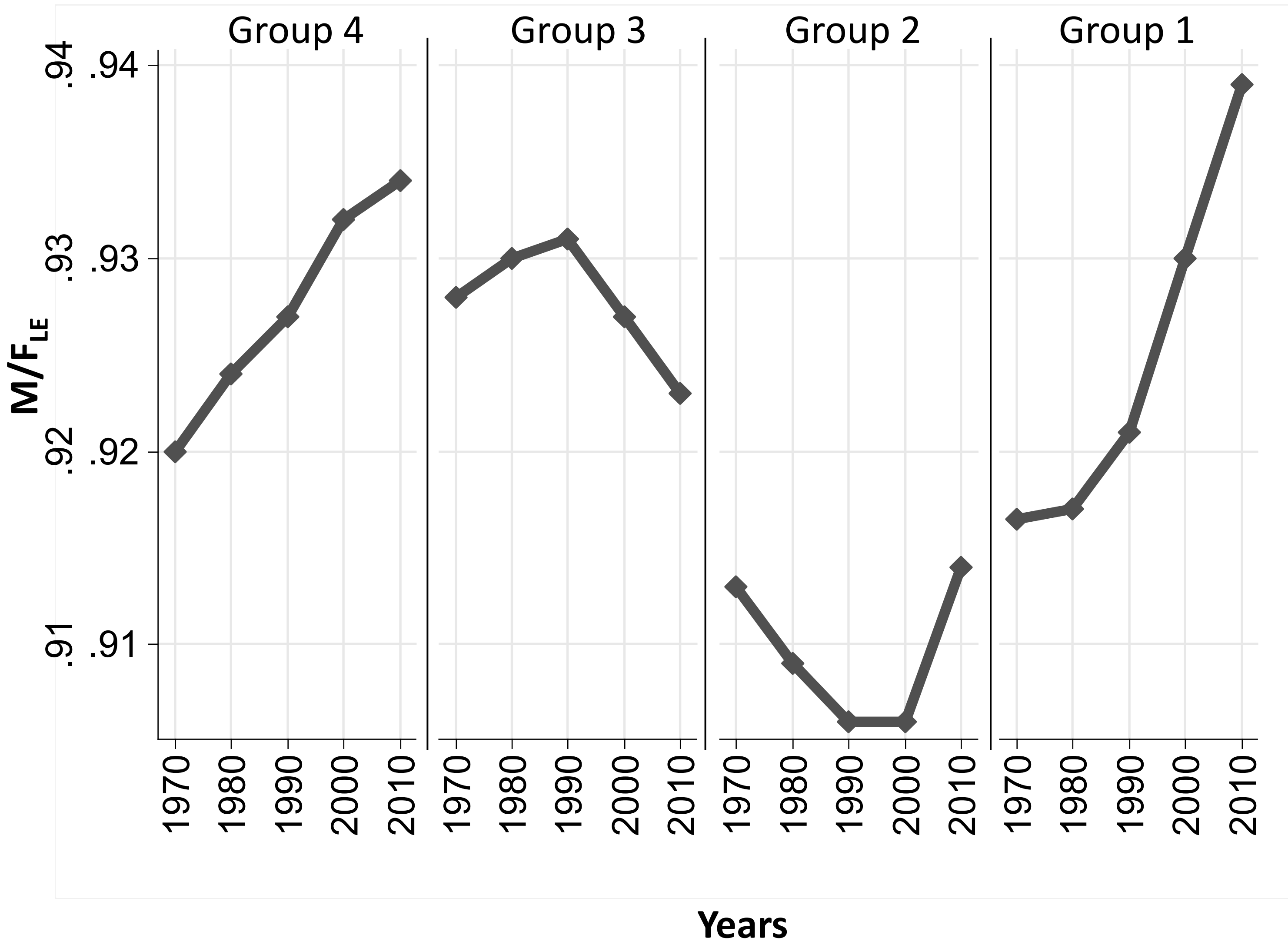
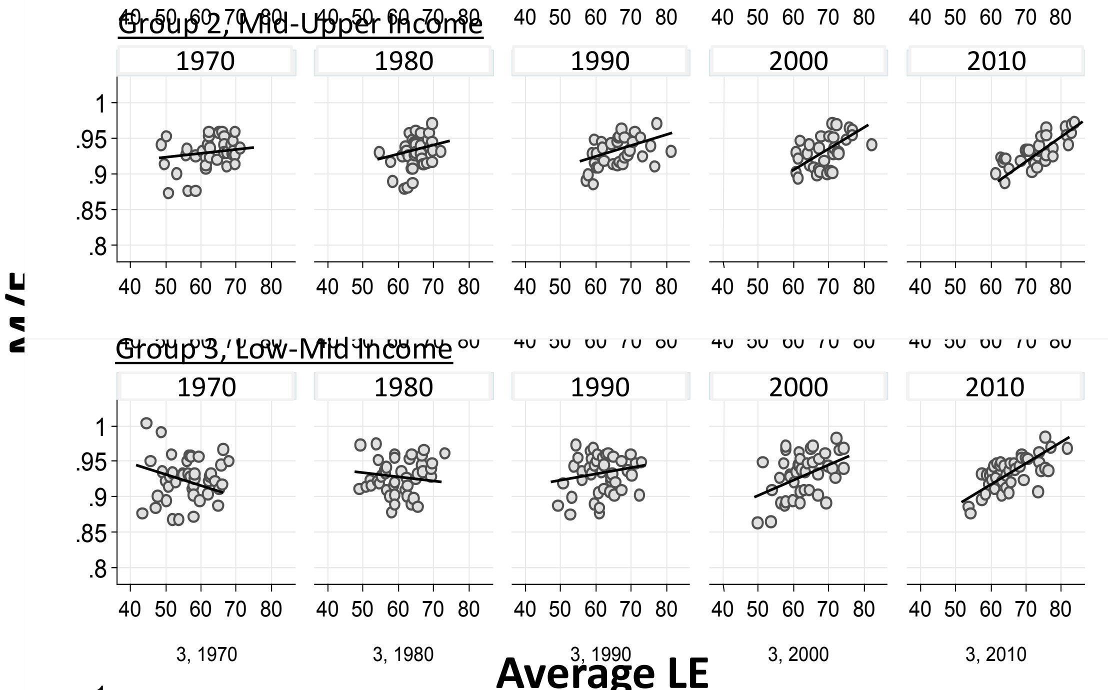


Figure 8: M/F_{LE} over Years, by Development Group



Group mean weighted by ½ log population of countries within group

Figure 9: M/F_{LE} vs Average LE for Countries in Groups 2 and 3, by Decade



Dependent Var: M/F_{LE}, Independent Var: LE

Year	Coef.	Std Err	t	p-value	ρs
1970	0.0004	0.0006	0.45	0.652	0.2300
1980	0.0006	0.0007	1.01	0.32	0.3576
1990	0.0011	0.0005	2.23	0.033	0.4178
2000	0.015	0.0005	2.93	0.006	0.5200
2010	0.0017	0.0003	5.69	<0.001	0.7810

Group 2

Year	Coef.	Std Err	t	p-value	ρs
1970	-0.0009	0.0009	-0.8	0.428	-0.0094
1980	-0.0004	0.0007	-0.45	0.655	-0.0125
1990	0.0005	0.0007	0.95	0.348	0.1122
2000	0.0011	0.0006	1.78	0.083	0.4550
2010	0.0016	0.0004	3.34	0.002	0.6877

Group 3

Figure 10: M/F_{S70} by Decade for IE Countries, 1950-2010

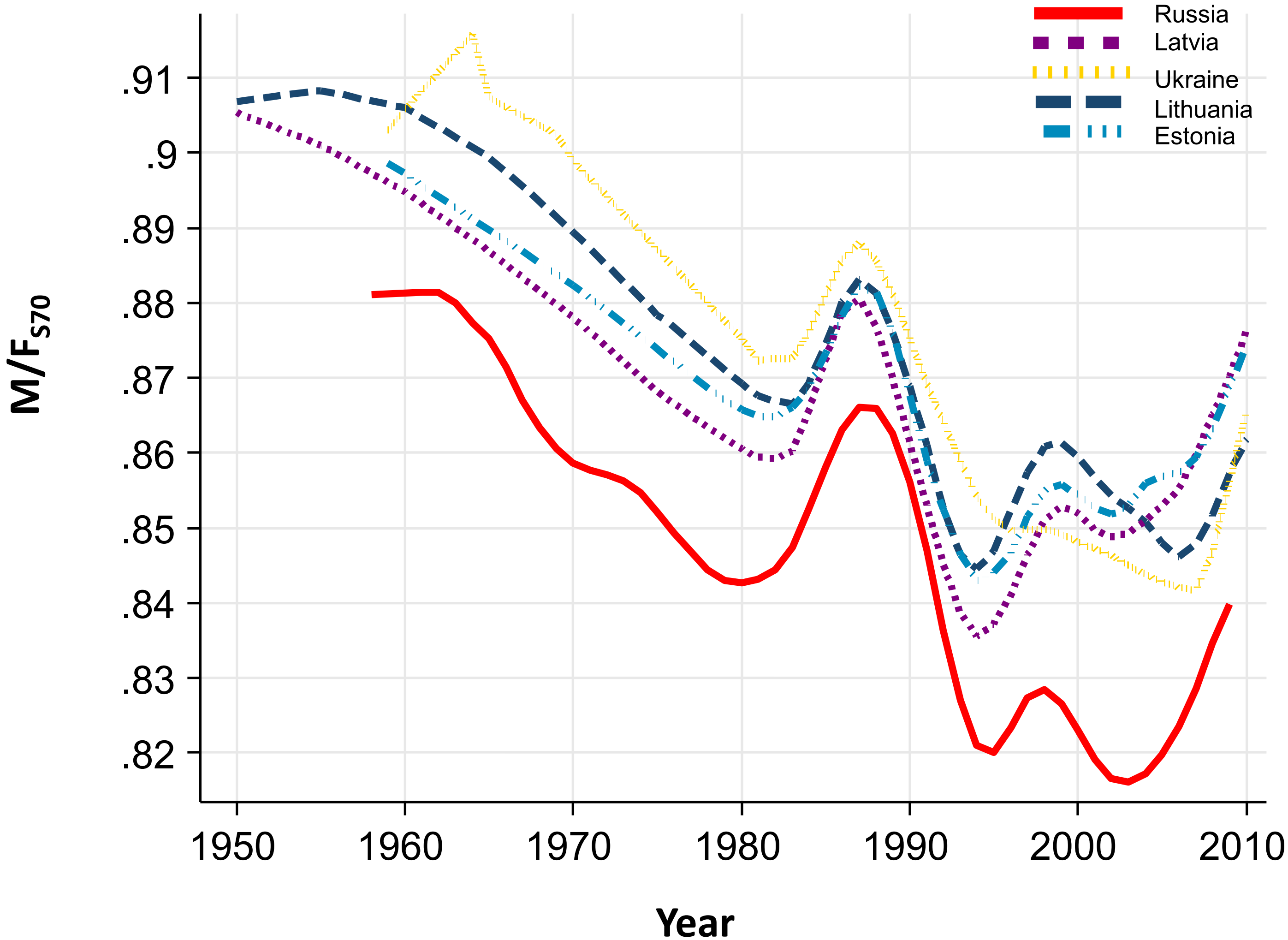


Figure 11: M/F_{LE} vs Income, by Japanese Prefecture

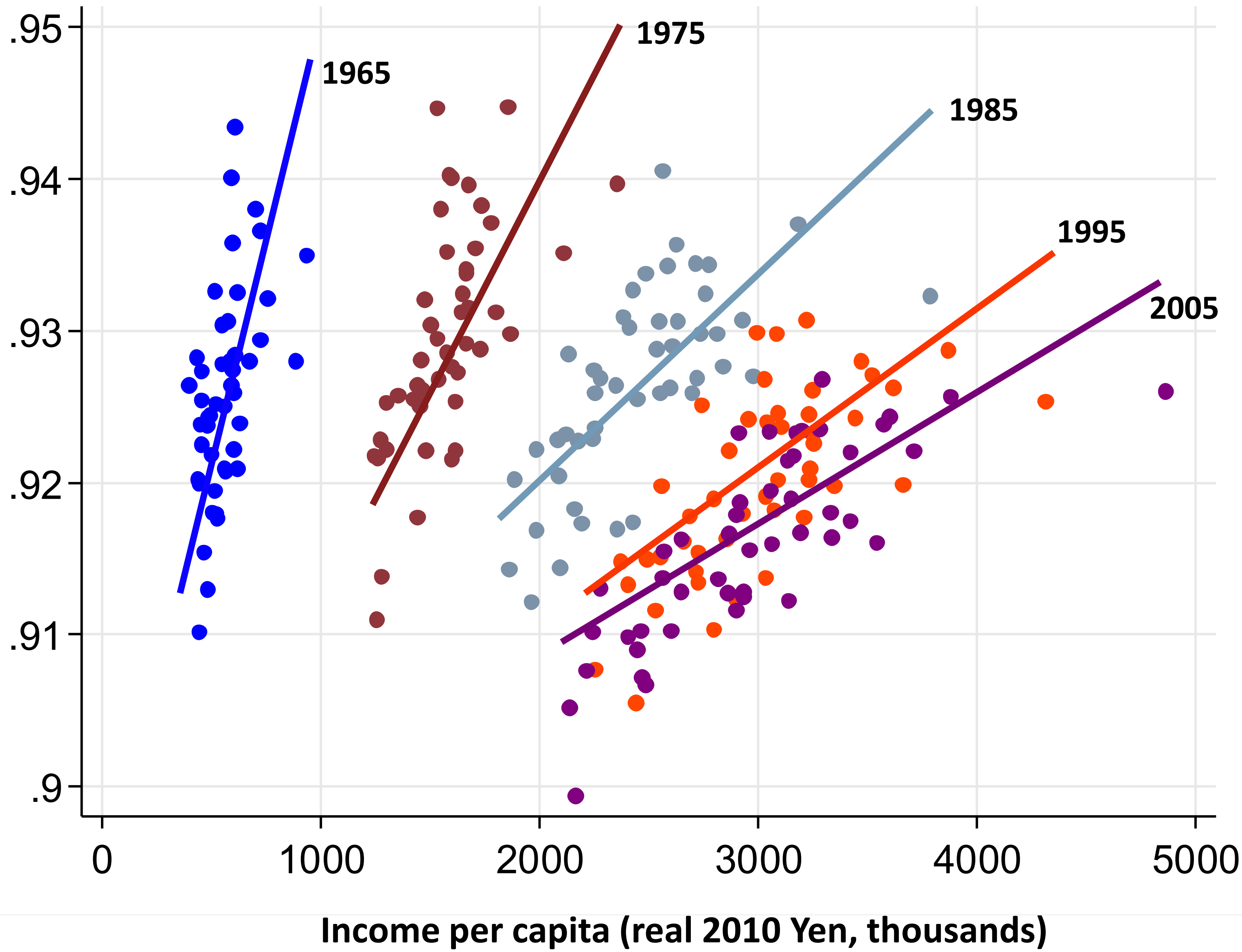
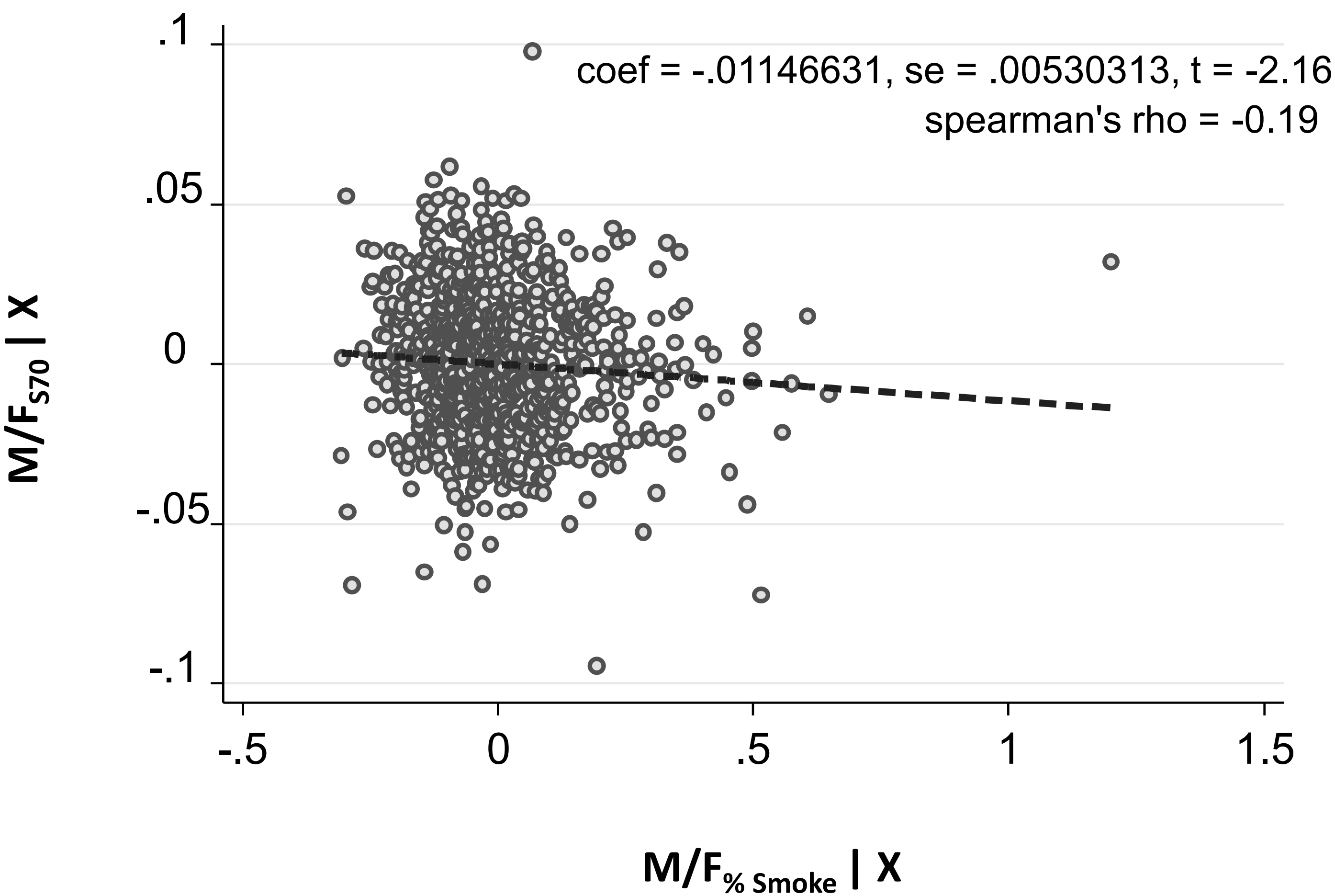
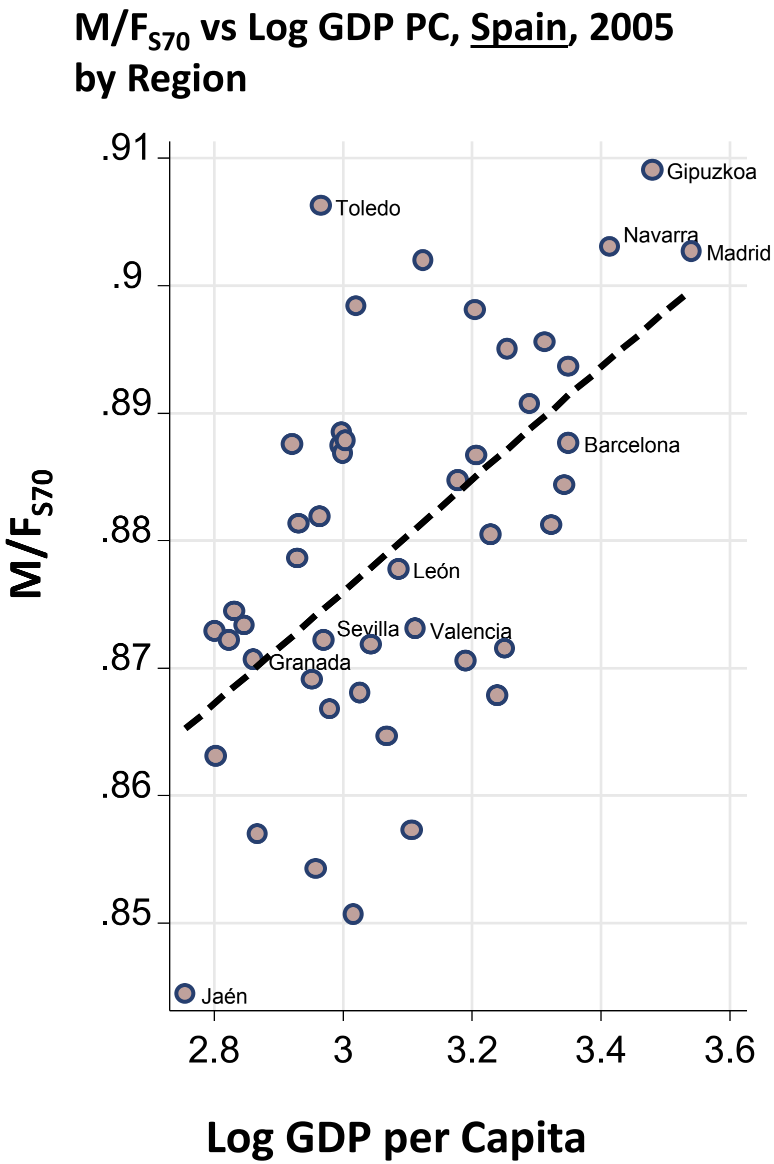


Figure S1: M/F_{S70} vs Excess Male Smoking (M/F Smoking Prevalence) after adjusting for Education, Income, Poverty, and Obesity, 2010 US Counties, Whites



X = % High School Grad, Average Income, % Poverty, % Obese, by County

Figure S2: M/F_{s70} v. log GDP for Spain and M/F_{LE} v. log Income for Japan (2005)



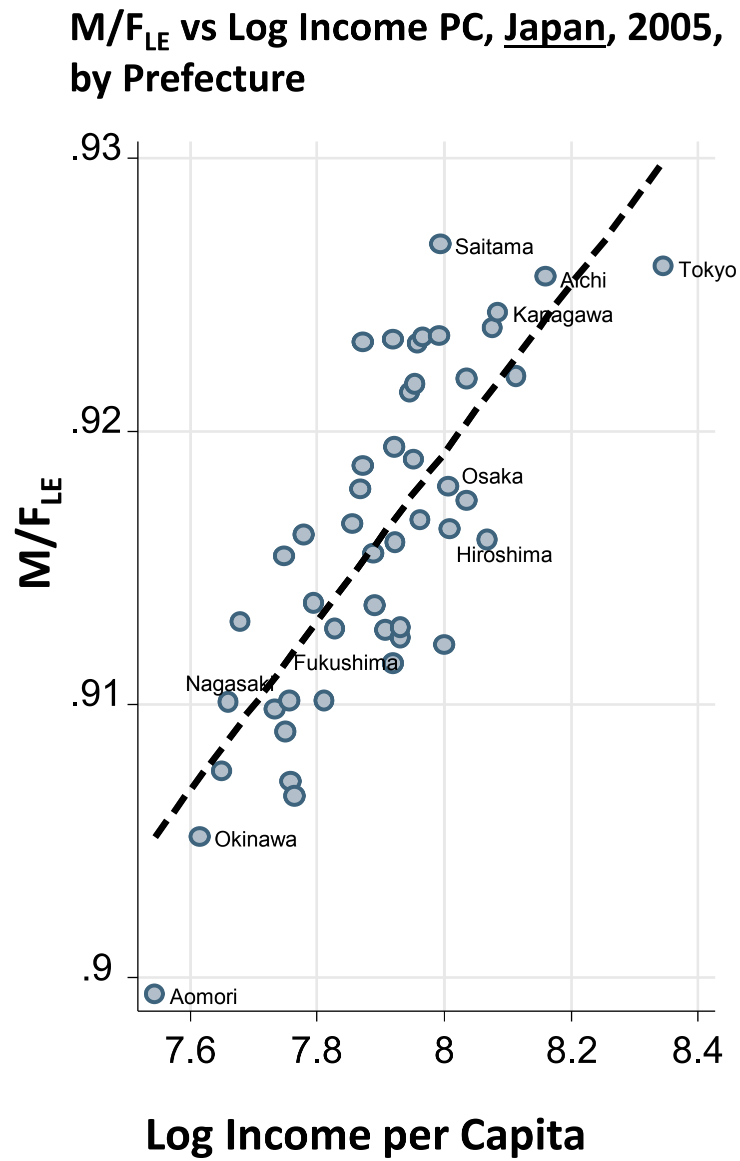
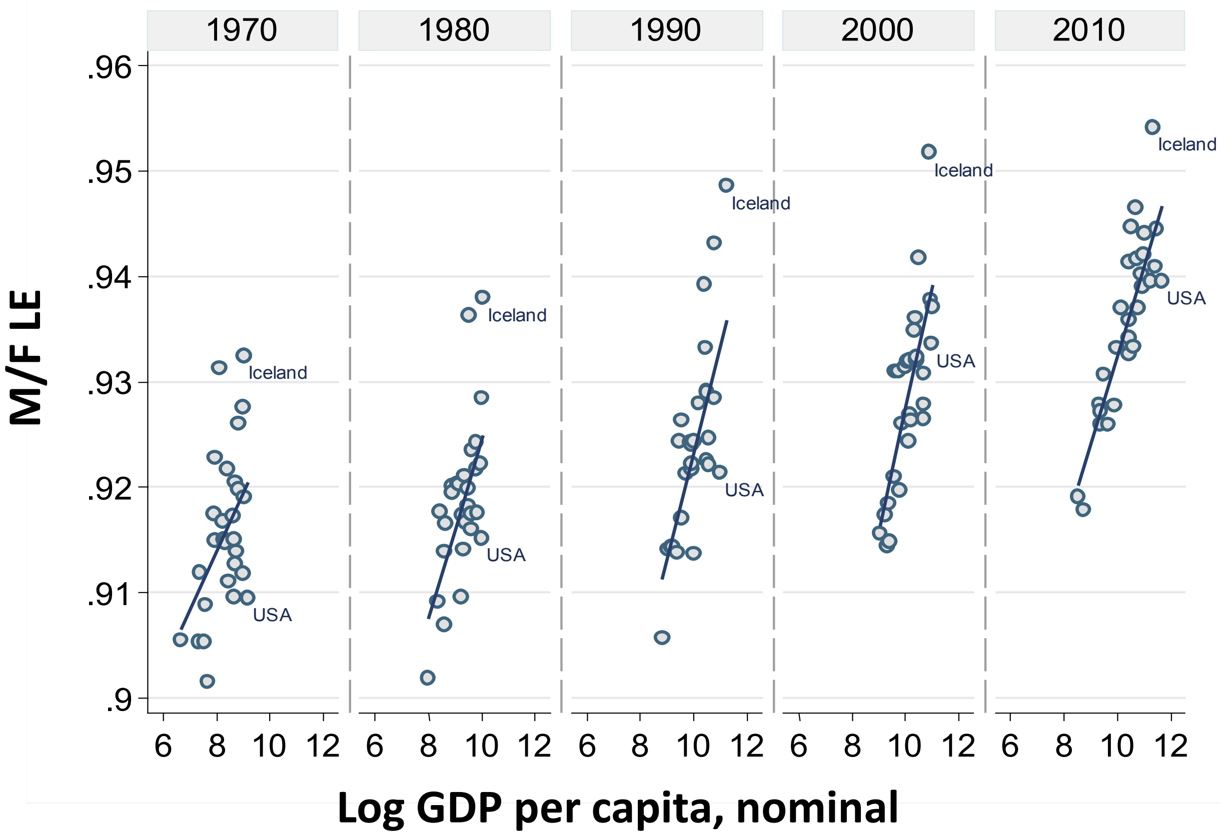
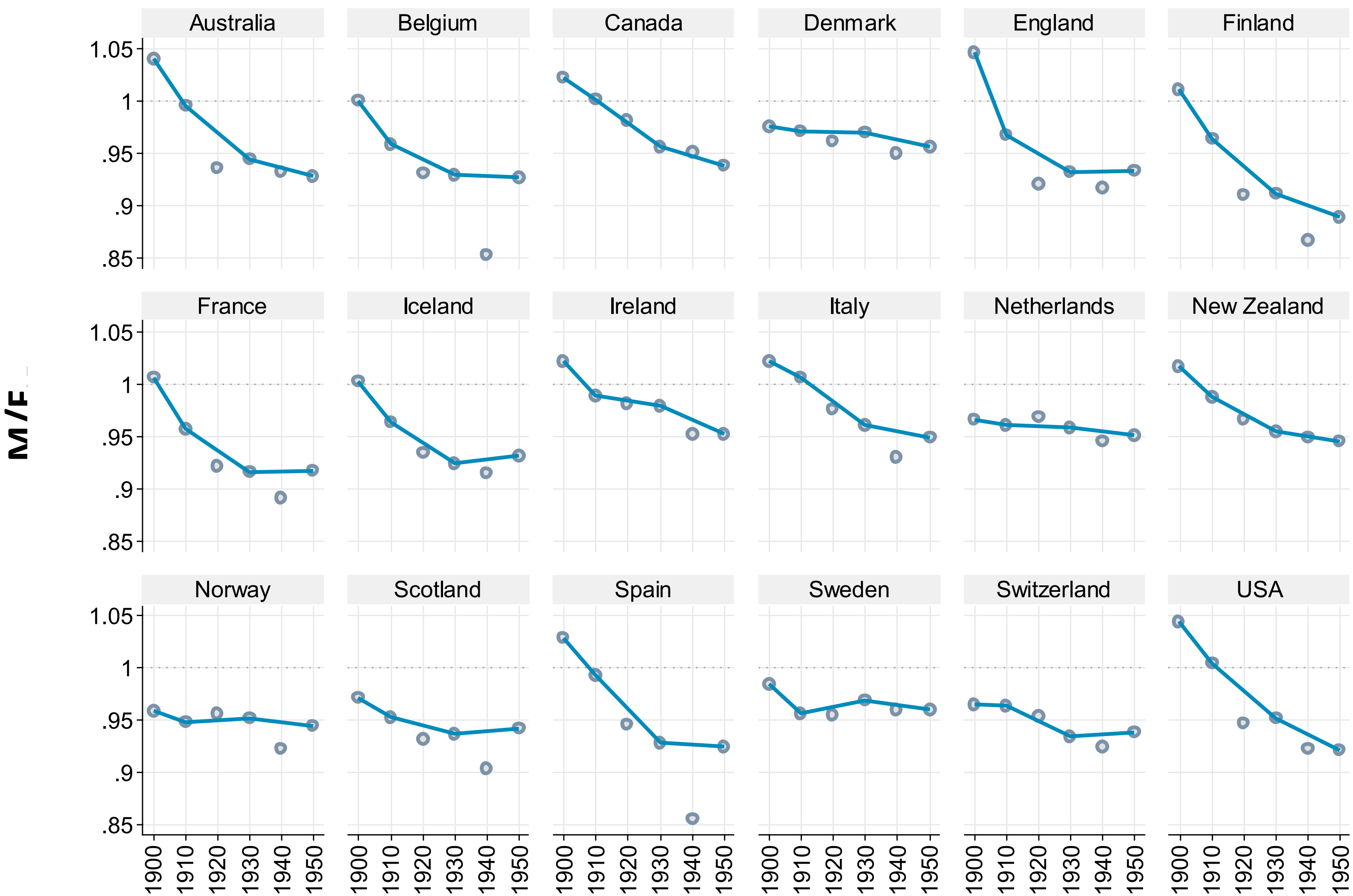


Figure S3: M/F_{LE} vs. Log PC GDP for Group 1 Countries, by Decade



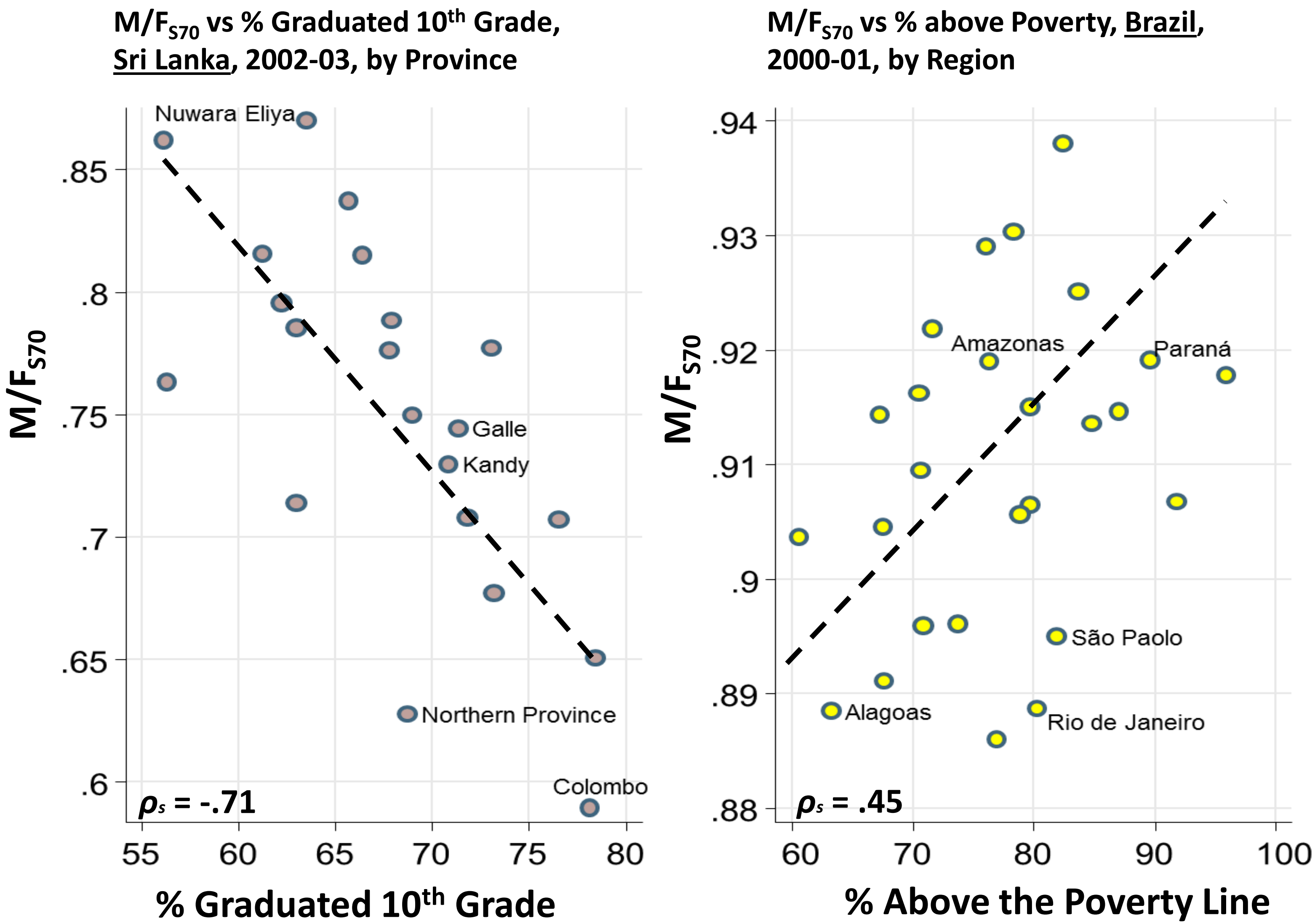
	Coef.	Std Err	t	p-value	ρ_s
1970	0.0068	0.0023	2.95	0.007	0.53
1980	0.0095	0.0022	4.33	<0.0001	0.67
1990	0.0120	0.0021	5.78	<0.0001	0.71
2000	0.0128	0.0020	6.51	<0.0001	0.86
2010	0.0096	0.0011	9.11	<0.0001	0.93

Figure S4: M/F_{LE} for 18 Developed Countries, 1900-1950



Note: Line does not connect values for 1920 and 1940, as those years had Spanish Influenza and World War Two.

Figure S5: M/F_{s70} v. education (% with 10th grade graduation) for Sri Lanka (2002) and M/F_{LE} v. % above poverty line for Brazil (2000)



Department of Census and Statistics District Report, Sri Lanka, 2002-03; 2000-01 Brazil Census

Figure S6: Maternal Mortality Rate over each Group, 1980-2010

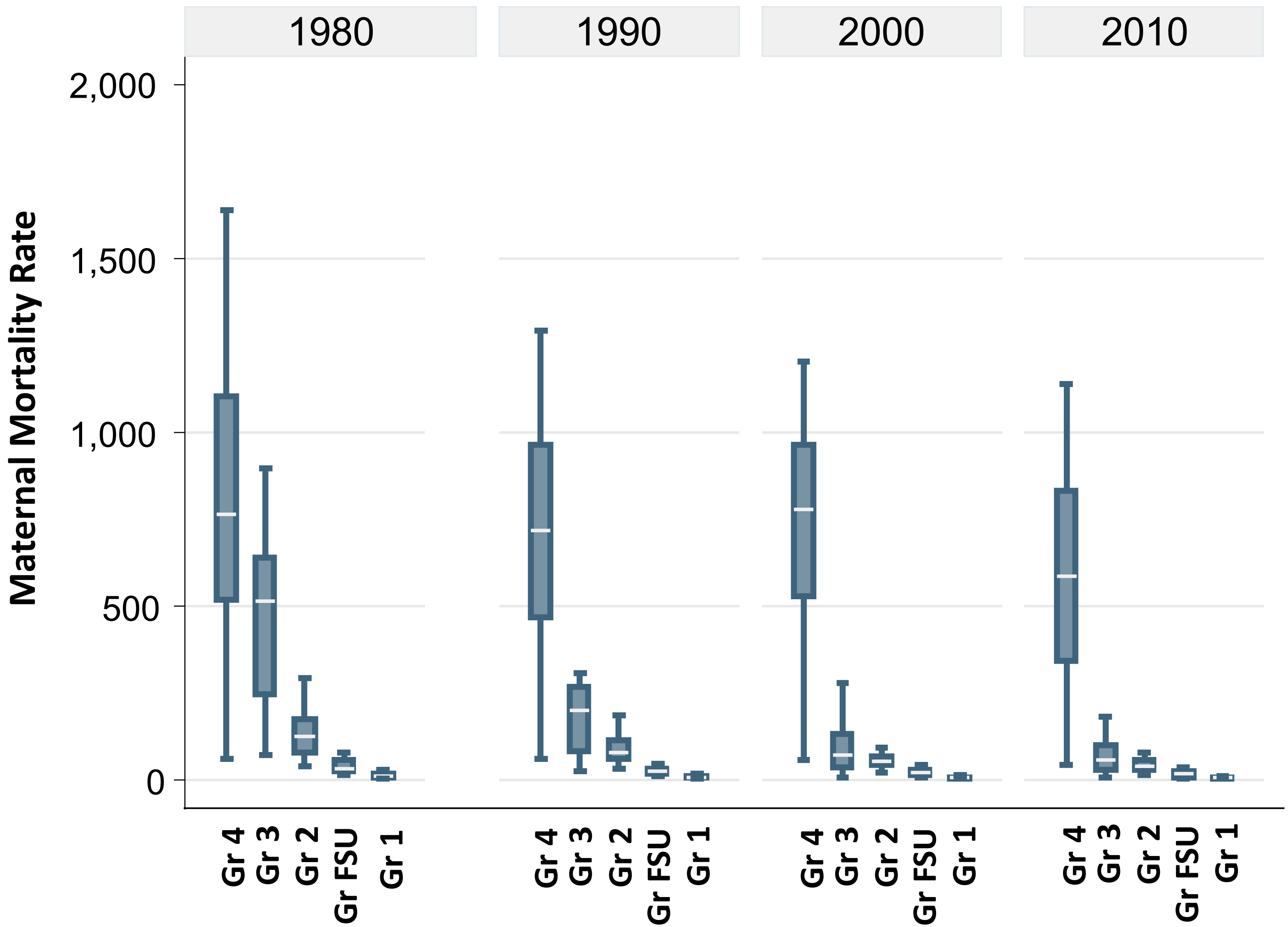
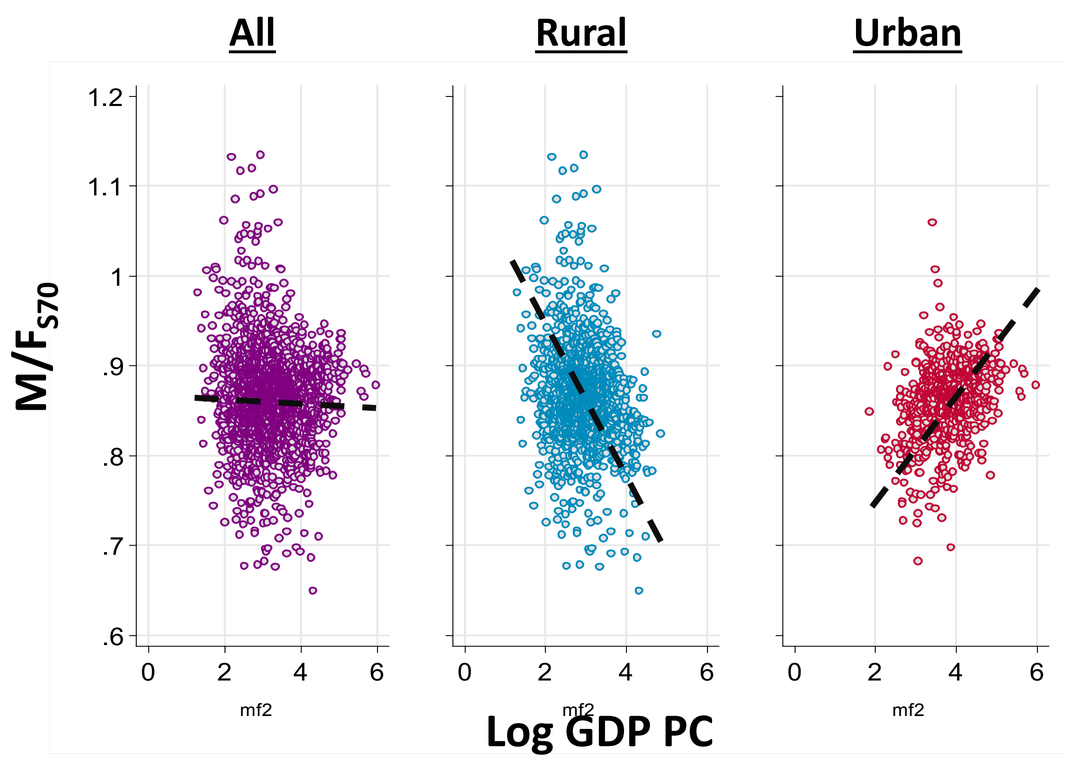


Figure S7: M/F$_{S70}$ vs Log GDP per capita, China Provinces, Stratified by Urban and Rural



Outcome	N	Coef.	Std Error	p-value	ρ_s
All M/F S70	2358	-0.01	0.003	0.006	-0.0199
Rural M/F S70	1610	-0.37	0.002	<0.0001	-0.2118
Urban M/F S70	748	0.44	0.002	<0.0001	-0.4564

Figure S8: M/F_{LE} by Country, 2000

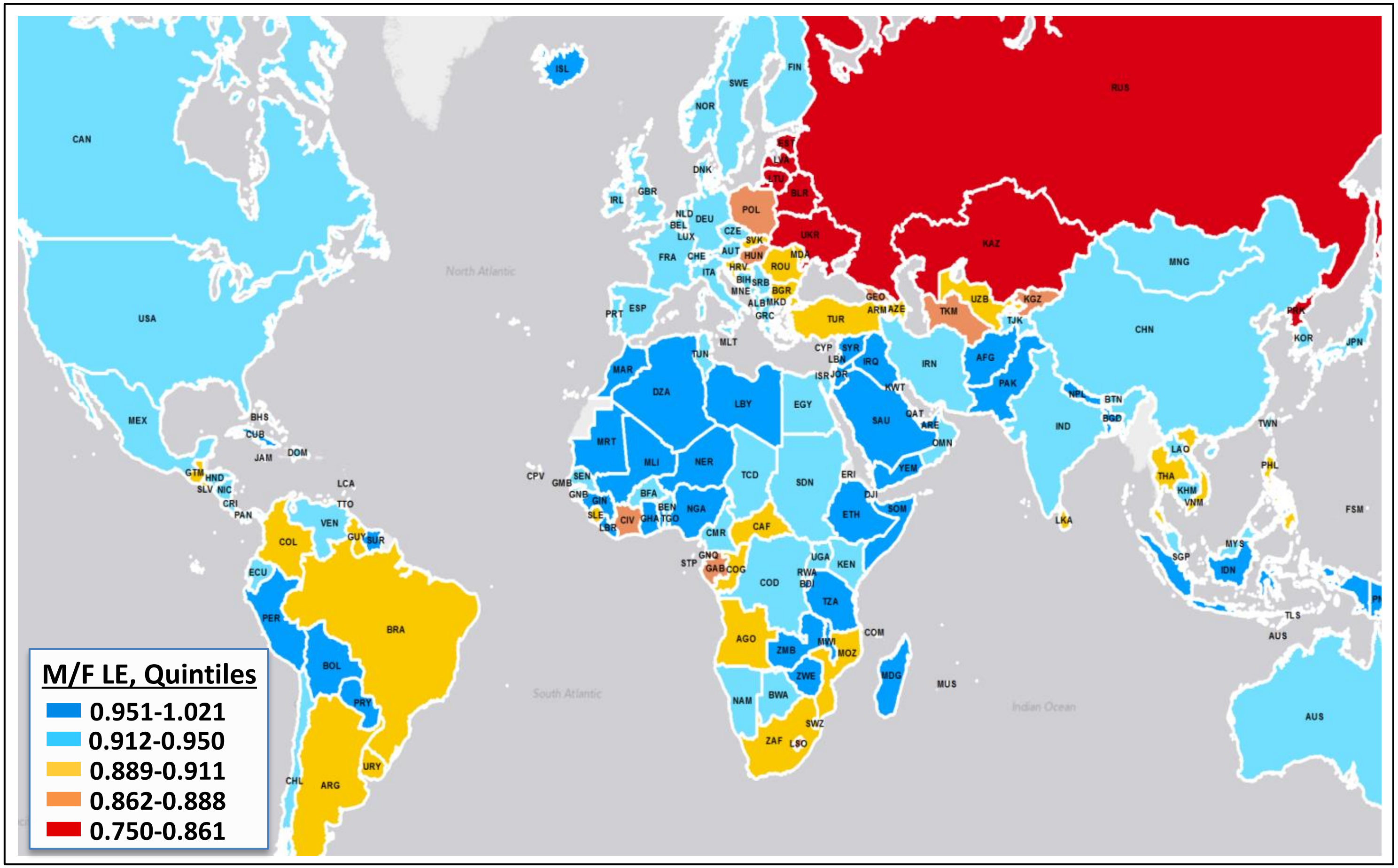
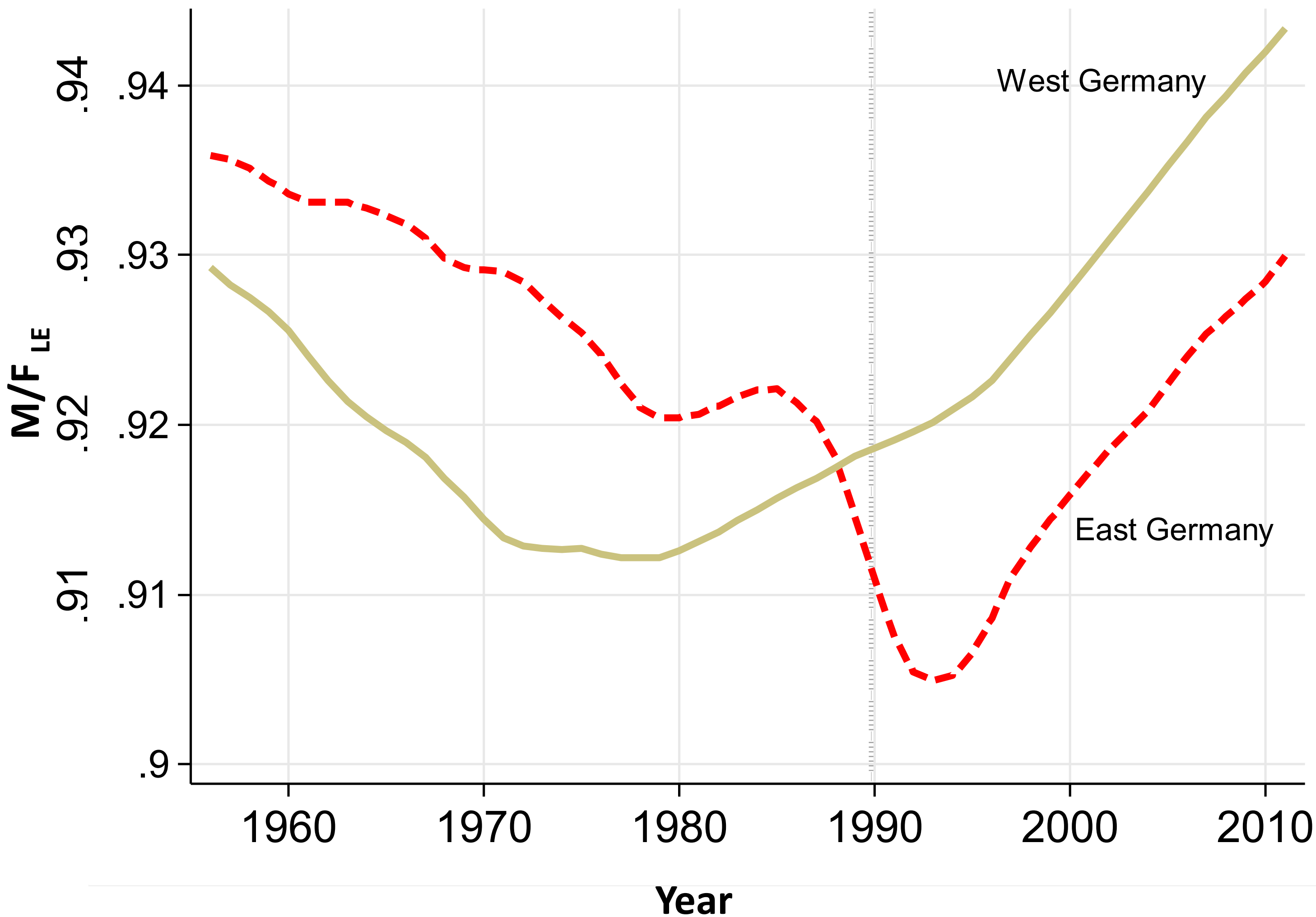
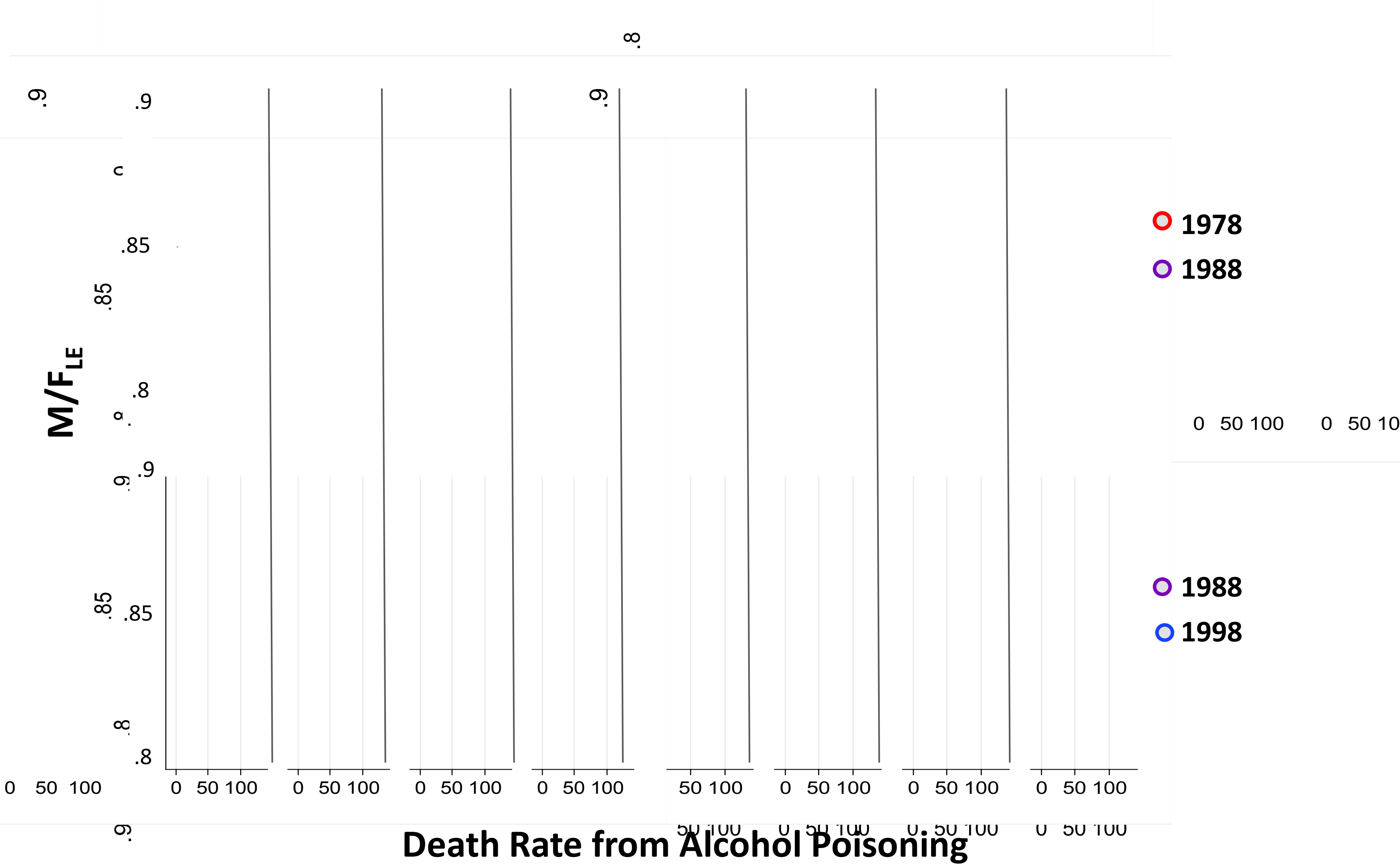


Figure S9: M/F_{LE} by Year, East and West Germany, 1958-2010



Vertical line represents fall of Berlin Wall

Figure S10: M/F_{LE} vs Alcohol Death Rate, by Oblast and Region, 1978 to 1988, 1988 to 1998



-Death Rates, per 100,000

-Regions N Cauc and South have highest Muslim populations

-Plots are at level of oblast, by region ordered geographically from SW to NE (same a most to least Muslim by % population)

Figure S11: M/F_{S70} vs per capita Log GDP for available Group IE Countries by Decade, 1980-2000