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SCIENCE ADVANCES | RESEARCH ARTICLE

EPIDEMIOLOGY

Unemployment and underemployment are causes of suicide

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Epidemiological studies indicate that labor underutilization and suicide are associated, yet it remains unclear whether this association is causal. We applied convergent cross mapping to test for causal effects of unemployment and underemployment on suicidal behavior, using monthly data on labor underutilization and suicide rates in Australia for the period 2004–2016. Our analyses provide evidence that rates of unemployment and underemployment were significant drivers of suicide mortality in Australia over the 13-year study period. Predictive modeling indicates that 19.9% of the ~32,000 suicides reported between 2004 and 2016 resulted directly from labor underutilization, including 3295 suicides attributable to unemployment and 3131 suicides attributable to underemployment. We conclude that economic policies prioritizing full employment should be considered integral to any comprehensive national suicide prevention strategy.

INTRODUCTION

Nearly 1 million people are estimated to die by suicide each year or, equivalently, one person every ~30 s (*1*). After road traffic injuries, suicide is the principal cause of mortality among adolescents and young adults aged 15 to 29 years, accounting for 8% of deaths reported for this age group annually (*2*). Although there is substantial evidence for an association between unemployment and suicide (*3*), it remains unclear whether this association is causal (i.e., unemployment drives suicidal behavior) or results primarily from the dependence of both variables on one or more confounding factors. Mental disorders, in particular, are a significant predictor of both suicide mortality and labor market outcomes (*4*, *5*), so that unemployment and suicide may be associated simply because having a mental disorder simultaneously increases the probability of suicidal behavior and of being unemployed (*6*). Moreover, while analyses of the effects of economic crises on population health indicate that substantial increases in unemployment are often accompanied by an increase in suicide mortality (*7*), there is also evidence that observed increases in suicide may precede pronounced economic disruption, suggesting a cause other than increasing unemployment (*8*). Determining the extent to which rates of labor underutilization (i.e., unemployment and underemployment rates) drive suicide mortality is critical not only for developing effective suicide prevention strategies but also for any proper assessment of the social and economic consequences of alternative economic policy decisions (*9*).

We applied convergent cross mapping (CCM) (*10*) to test for causal effects of unemployment and underemployment on suicidal behavior, using monthly data on labor underutilization rates and suicide mortality in Australia for the period 2004 to 2016 (Fig. 1). Given a nonlinear dynamic system in which a causal variable x influences a dependent variable y (either directly or indirectly), a historical time series of y, $\{y\} = \{y(t_1), \ldots, y(t_L)\}$, will contain information about and can therefore be used to predict past values of x. More specifically, local neighbourhoods on an attractor manifold M_y reconstructed from $\{y\}$ via time delay embedding will map to local neighbourhoods on an attractor manifold M_x reconstructed from the corresponding time series for x, $\{x\} = \{x(t_1), \ldots, x(t_L)\}$, so that values in $\{x\}$ can be estimated from M_y using simplex projection [a procedure termed cross mapping (*10*)]. As time series length, L, increases, the attractor manifolds M_y and M_x become denser or fill in (i.e., the distance between neighboring points declines), increasing the reliability with which values in $\{x\}$ can be estimated from M_y. Crucially, where x and y are correlated only because they depend on a shared cause (i.e., x does not drive y), local neighborhoods on M_y are not expected to map to local neighborhoods on M_x, and accordingly there is no expectation that values in $\{x\}$ will be estimated more reliably as L is increased (*10*). An ability to estimate values of x from M_y that improves with increasing time series length (convergence) therefore provides evidence for a causal effect of x on y.

RESULTS AND DISCUSSION

The results of CCM analyses examining the potential dependence of suicide mortality on rates of unemployment and underemployment are presented in Fig. 2. The panels on the left show correlations, measured using the Pearson product-moment correlation coefficient, ρ, between the observed unemployment and underemployment rates [$u(t)$ and $v(t)$, respectively] and the unemployment and underemployment rates estimated via cross mapping using the suicide mortality data [$\hat{u}(t)\,|\,M_s$ and $\hat{v}(t)\,|\,M_s$, respectively, where M_s denotes an attractor manifold reconstructed from the suicide data; see above]. As the length of the time series used to reconstruct M_s (i.e., L) increases, ρ also increases for both unemployment and underemployment, indicating improving estimation of the observed underutilization rates. Null distributions for ρ derived from surrogate unemployment and underemployment time series [10^3 replicates, each generated by randomizing the phases of a Fourier transform of the observed time series (*11*)], are presented in the panels on the right. The proportions of

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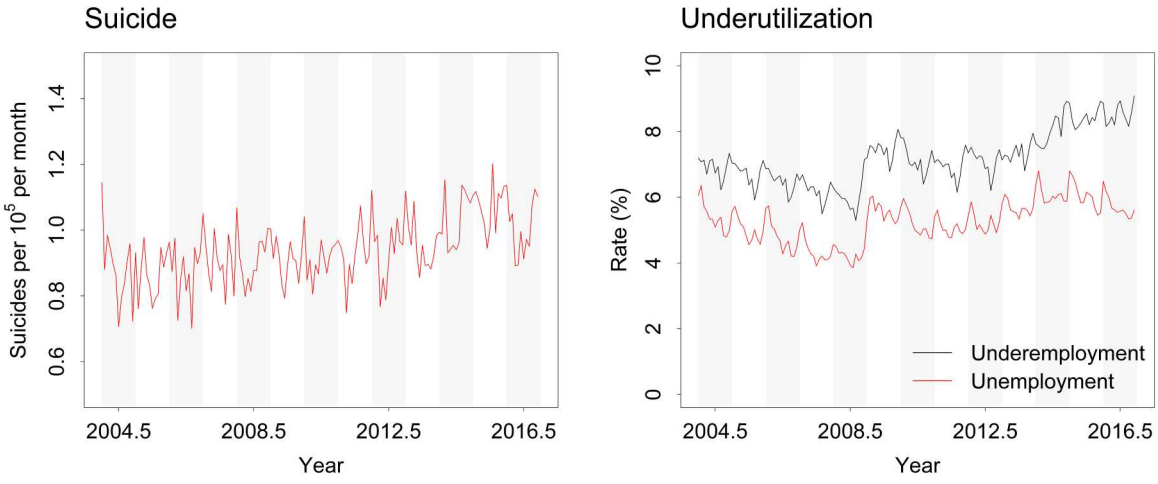

Fig. 1. Suicide mortality and labor underutilization rate time series for Australia used to test for causal effects of unemployment and underemployment on suicidal behavior. See Materials and Methods for details. Gray shading indicates even years.

surrogate time series for which ρ (calculated at the maximum value of L) exceeds the observed value (i.e., for the empirical time series, indicated by the vertical red lines) are 0.023 for unemployment and 0.002 for underemployment. Thus, the predictability of both $u(t)$ and $v(t)$ is statistically significant (at the 0.05 and 0.01 levels, respectively) and increases with increasing L, indicating that unemployment and underemployment drive suicide mortality (*10*).

As a means of quantifying the contribution of labor underutilization to suicide mortality, we estimated numbers of suicides per month in the absence of unemployment and underemployment using a predictive model fitted to the suicide mortality time series (see left panel of Fig. 3). The number of suicides per month at time t, $s(t)$, was assumed to follow a negative binomial distribution with an expected value equal to $g(t)h(t)\lambda(t)P(t)$, where $g(t) = 1 + u(t)F(t)P(t)^{-1}(\theta_u - 1)$ and $h(t) = 1 + v(t)F(t)P(t)^{-1}(\theta_v - 1)$ are the time-specific effects of unemployment and underemployment, respectively, on the monthly suicide rate; $\lambda(t) = \lambda(t_0) + \delta(t - t_0) + m(t)$ is the per capita suicide rate among people who are neither unemployed nor underemployed at time t; δ is the increase in λ per year due to causes other than labor underutilization; $m(t) \sim N(0, \sigma^2)$ is a month-specific effect included to model seasonal variation in the suicide rate unrelated to employment status; $F(t)$ and $P(t)$ are respectively the labor force and the total population at time t; and θ_u and θ_v are the suicide hazard ratios for unemployment and underemployment, respectively. Numbers of suicides in the absence of labor underutilization were derived from the fitted model by setting $u(t)$ and $v(t)$ to zero for all t. The right panel of Fig. 3 shows estimated numbers of suicides per month attributable to unemployment and underemployment, obtained by subtracting the numbers of suicides per month inferred for the counterfactual scenario (i.e., no underutilization) from the total numbers of suicides predicted assuming the observed unemployment and underemployment rates. Approximately 1 in 5 of the 32,329 suicides predicted over the study period (2004–2016, inclusive) are estimated to result from labor underutilization (6426 suicides or 19.9%), including 3295 suicides attributable to unemployment (10.2% of total suicide mortality) and 3131 suicides attributable to underemployment (9.7%).

Our CCM results are consistent with the results of prospective epidemiological studies indicating that transitions from employment to unemployment tend to produce a significant increase in psychological distress [a principal risk factor for suicide mortality and intentional self-harm (*12*)], while transitions in the reverse direction are associated with improvement in mental health (*13*). Prospective studies similarly indicate that involuntary part-time employment and insecure (involuntary temporary) employment are significant predictors of increased symptoms of psychological distress (*14*–*16*), consistent with our results for underemployment. Unemployment and underemployment are associated with multiple potential risk factors for poor psychological health, including financial hardship and poverty (*17*–*19*), lower self-perceived social status (*20*, *21*), and reduced social network size and availability of social (practical and emotional) support [at least for people aged 50 years or more (*22*)]. Moreover, there is evidence that socioeconomic deprivation (which depends strongly on employment status and income) is associated with poorer mental health treatment outcomes, so that unemployment and underemployment may not only increase the incidence of psychological distress but could also lead to greater severity and persistence of symptoms among those receiving care [psychotherapy and/or pharmacotherapy (*23*, *24*)].

Although the CCM results presented in Fig. 2 provide evidence that observed associations between the suicide mortality rate and unemployment and underemployment are not simply due to shared dependence on a prior cause (e.g., mental disorder prevalence), it should be noted that the potential for confounding still exists in our predictive modeling analysis [as it does in other statistical modeling analyses; e.g., (*3*)]. Assuming that suicide mortality and labor underutilization are both (causally) dependent on the prevalence of psychological distress and associated mental disorders (*4*, *5*), unbiased estimation of the contributions of unemployment and underemployment to total suicide mortality at time t would require that we adjust for prior mental disorder prevalence (i.e., measured at time $t - k$, where k is a positive integer; see fig. S7); however, monthly, or even yearly, data on the prevalence of mental disorders (or, alternatively, psychological distress) in Australia are unavailable for the study period, so this adjustment was

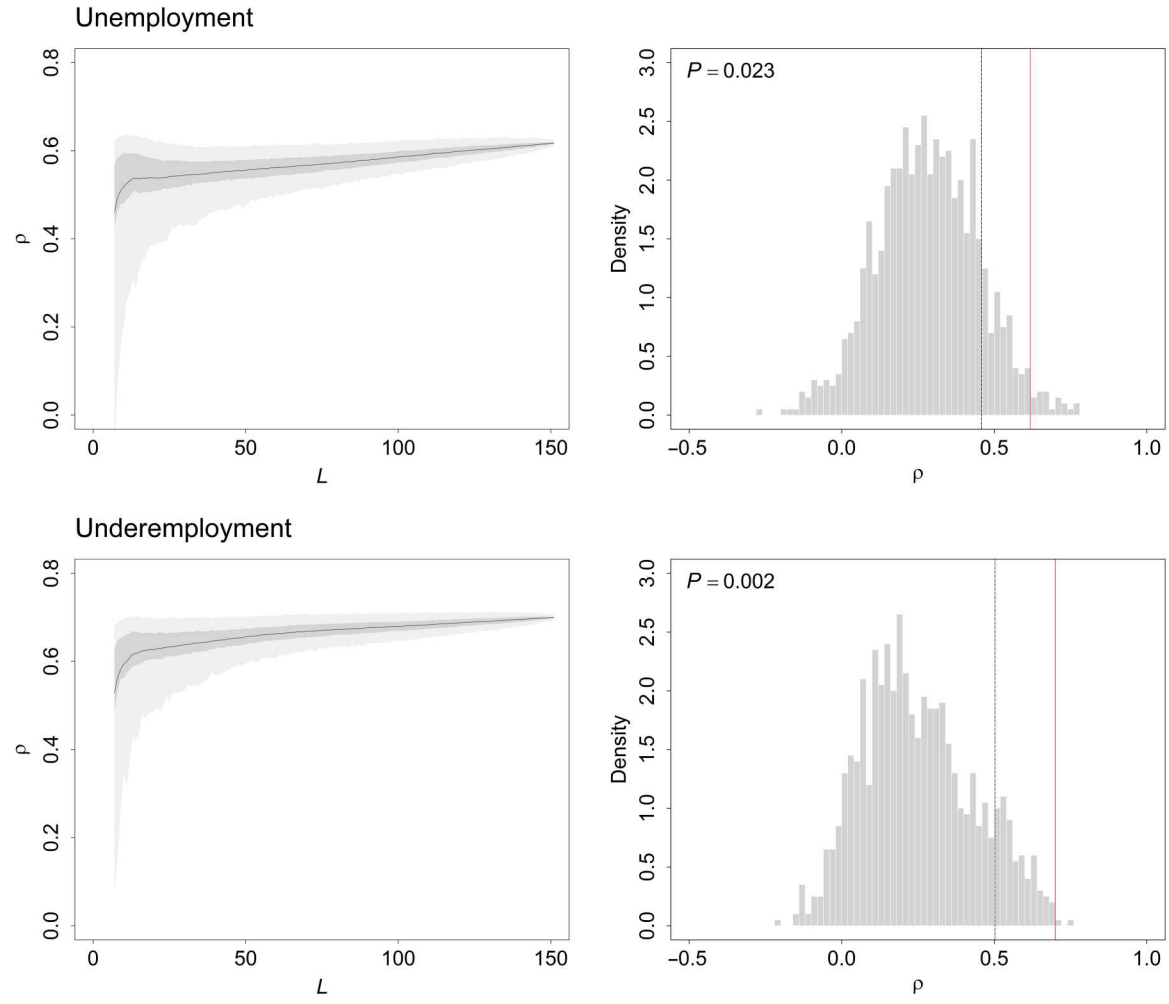

Fig. 2. CCM results (embedding dimension, *E*, 5). Left panels: Correlations, measured using the Pearson product-moment correlation coefficient, ρ, between the observed unemployment and underemployment rates and unemployment and underemployment rates estimated via cross mapping using the suicide mortality data. Mean correlations (solid lines) and 95 and 50% intervals (light and dark shading, respectively) for each value of *L* were derived from 10^3 libraries randomly sampled (with replacement) from the suicide mortality rate data. Right panels: Null distributions for ρ (at the maximum value of *L*) derived from 10^3 surrogate unemployment and underemployment time series, each generated by randomizing the phases of a Fourier transform of the observed time series (*11*). The proportions of surrogate time series for which ρ exceeds the observed value (i.e., for the empirical time series, indicated by the vertical red lines) are in the top left corner of each plot. Correlations between the suicide time series and the unemployment and underemployment time series (0.458 and 0.502, respectively) are indicated by the dashed vertical lines (plotted in black).

not possible. As a consequence, it is probable that our predictive modeling overestimates the numbers of suicides directly attributable to unemployment and underemployment, at least to some extent. Although the magnitude of this overestimation is unclear, CCM analyses using simulated numbers of suicides derived from the fitted predictive model yield results similar to those obtained for the empirical suicide data in Fig. 1 (see fig. S8), suggesting that our estimates of the effects of unemployment and underemployment on suicide mortality (the hazard ratios θ_u and θ_v) are not seriously biased.

Persistently high unemployment (above ~2%) and increasing underemployment in Australia and most other Organization for Economic Co-operation and Development member countries are largely a consequence of insufficient aggregate demand attributable to economic policy approaches prioritizing the containment of national government deficits (*25*, *26*). Although restricting net government expenditure has generally been considered necessary for maintaining low inflation and is frequently equated with responsible economic management, alternative policy approaches relying on the creation of an employment buffer stock (through the introduction of a job guarantee) have been proposed that are capable of achieving price stability while simultaneously eliminating labor underutilization (*26*–*28*). The CCM and predictive modeling results presented here suggest that the ability of these alternative policy approaches to reduce suicide mortality (by eradicating unemployment and underemployment) may be substantially greater than that of evidence-based clinical and health services planning interventions (*29*, *30*). Dynamic modeling analyses indicate, for example, that routine provision of intensive post-suicide attempt care has the potential to reduce total (cumulative) numbers of suicides in the

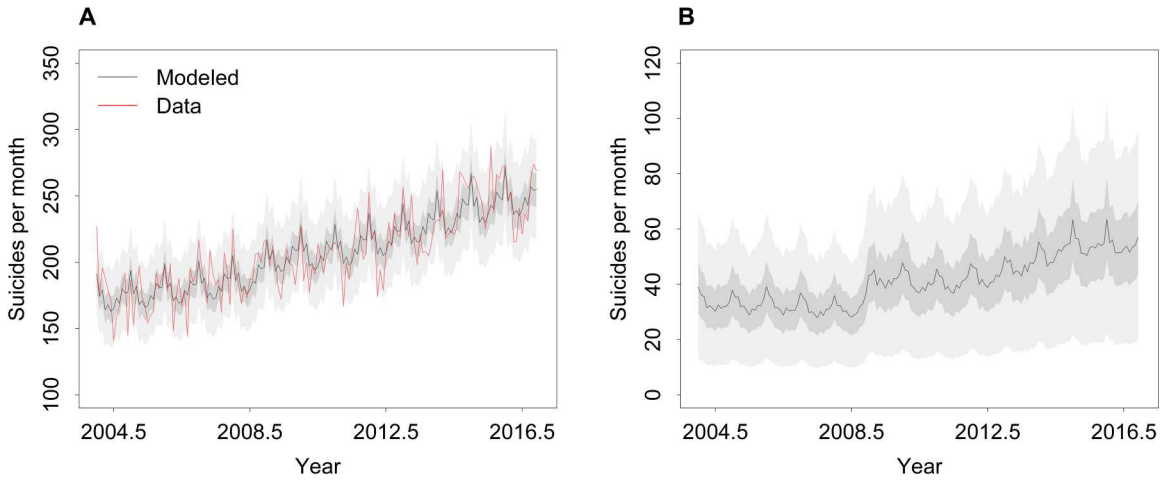

Fig. 3. Predictive modeling results. (**A**) Empirical numbers of suicides reported per month (red line) and corresponding numbers of suicides predicted from the fitted model (see Results and Discussion). Median predicted numbers of suicides per month (dark gray line) and 95 and 50% intervals (light and dark gray shading, respectively) were calculated from 8000 simulated time series, each generated using a different parameter vector sampled in the Markov chain Monte Carlo (MCMC) analysis (see Materials and Methods). (**B**) Numbers of suicides per month directly attributable to labor underutilization, estimated by subtracting predicted numbers of suicides per month under a counterfactual scenario in which the unemployment and underemployment rates are equal to zero for all time points from the numbers of suicides predicted assuming the observed unemployment and underemployment rates. Median estimates (dark gray line) and 95 and 50% intervals (light and dark gray shading, respectively) for each time point were derived from expected numbers of suicides calculated for each of the 8000 parameter vectors sampled in the MCMC analysis (see Materials and Methods).

Australian state of New South Wales by 6.8 to 7.0% over a 10-year period (i.e., less than the 19.9% of suicides we estimate could be prevented over a similar period by eliminating underutilization; see Fig. 3), while safety planning and increases in specialized mental health services capacity are projected to reduce suicide mortality by up to 9.9 and 4.7%, respectively (*30*). The adoption of economic policies ensuring the availability of adequate employment for every person seeking work may therefore be among the most effective means available of reducing the immense personal, social, and economic costs of intentional self-harm and suicide and should be considered a core goal of any comprehensive national suicide prevention strategy.

MATERIALS AND METHODS

Suicide and labor force data

National data on numbers of suicides per month (all ages; International Classification of Diseases 10th Revision cause of death codes X60-84, Y87.0) for the period of 1 January 2004 to 31 December 2019 were provided by the Australian Institute of Health and Welfare. At the time of extraction, data for 2017–2019 were subject to revision and so were excluded from our analyses (i.e., we used data for the period 1 January 2004 to 31 December 2016 only; see Fig. 3, left panel). Monthly unemployment, underemployment, and participation rate estimates (original, unadjusted, series) were derived from official labor force statistics published by the Australian Bureau of Statistics (*31*). The unemployment rate, $u(t)$, is equal to the number of people aged 15 years or more who are not currently employed but are actively seeking paid work divided by the total number of people participating in the labor market [i.e., the labor force, $F(t)$, comprising people aged 15 years or more who are either employed or unemployed]. Underemployment is defined to include people aged 15 years and above working less than 35 hours per week who are willing and able to work additional hours (time-related underemployment); the underemployment rate, $v(t)$, is equal to the number of underemployed people divided by the total labor force. Monthly population estimates, $P(t)$, used in calculating suicide rates (per 10^5 population; see Fig. 1, left panel) and the proportions of people who are unemployed and underemployed [i.e., $u(t)F(t)P(t)^{-1}$ and $v(t)F(t)P(t)^{-1}$, respectively] were derived from quarterly population data published by the Australian Bureau of Statistics (*32*) via linear interpolation.

Convergent cross mapping

CCM (*10*) was performed using rEDM version 1.7.4 (available at https://ha0ye.github.io/rEDM/index.html). We selected an appropriate embedding dimension, E (the number of delay coordinates), for attractor manifold reconstruction using the approach described in (*33*). Briefly, this involved assessing the reliability of one-step ahead forecasts of the monthly suicide mortality rate (per 10^5 population) generated via simplex projection for varying values of E and identifying the embedding dimension yielding the most reliable forecasts (i.e., the value of E yielding the highest correlation between the observed and forecasted rates for the entire time series). The results of CCM analyses using values of E above and below the selected (optimal) embedding dimension ($E = 5$; see fig. S1) are qualitatively similar to those presented in Fig. 2 (figs. S2 and S3). S-map analysis (*34*) indicates that the reliability of monthly suicide rate forecasts improves as the degree of local weighting is increased from 0 (i.e., no local weighting; see fig. S1, right panel), providing evidence for nonlinear, or state-dependent, dynamics. Pearson correlation coefficient (ρ) means and intervals (95 and 50%) for each value of L calculated in the CCM analyses were derived from 10^3 libraries randomly sampled (with replacement) from the suicide mortality rate data. For all analyses

(univariate forecasting using simplex projection, S-map analysis, and CCM), we specified a time lag for delay embedding of $\tau = 1$.

Predictive modeling

The predictive model used for estimating numbers of suicides per month in the absence of unemployment and underemployment was fitted to the suicide mortality time series via Bayesian Markov chain Monte Carlo (MCMC) simulation. MCMC sampling was performed using Stan version 2.21.2 (available at https://mc-stan.org/), specifying weakly informative prior distributions for all model parameters (table S1). We ran four separate Markov chains, each initialized with parameter values sampled from the joint prior distribution, for 4000 iterations and used the final 2000 samples from each chain (8000 samples combined) for posterior inference (i.e., the initial half of each chain was discarded as warm-up). Potential scale reduction factors ($\hat{R}$) calculated for all parameters were less than 1.01, indicating approximate convergence to the posterior distribution (*35*), and effective sample sizes ($\hat{n}_{\text{eff}}$) exceeded 10^3 in all cases. Trace plots and marginal posterior distributions for selected model parameters are shown in fig. S4. Posterior predictive checking using the χ^2 discrepancy measure (*35*, *36*) yielded a posterior predictive P value of 0.45, indicating that the model provides an acceptable fit to the suicide mortality data (see fig. S5).

Supplementary Materials

This PDF file includes:

Figs. S1 to S8
Table S1
Legend for data file S1
References

Other Supplementary Material for this manuscript includes the following:

Data file S1

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