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The Curve

In a time of great fear and anxiety, one welcome surprise for me was the emergence of the phrase "flatten the curve." Those of us with a modicum of mathematical training usually have our ears pricked and tongues sharpened for even the slightest misuse of mathematical concepts (the regular deployment of "exponential" is a regrettable case in point), and curves are in general quite tricky. Even a recent anthology, Julian Havil's *Curves for the Mathematically Curious*, spends two hundred pages discussing curves without offering a definition. Havil cites mathematician Felix Klein's observation, "Everyone knows what a curve is, until he has studied enough mathematics to become confused through the countless number of possible exceptions."[1]

Calls to "flatten the curve" in 2020 seemed simple enough, however: reduce the daily SARS-CoV-2 case-load so that the number of new infections never exceeds the capacity of the health care system. If time is plotted on the x-axis, and daily numbers of new infections on the y-axis, an intervention such as a stay-at-home order can slow down transmission rates enough to flatten the graph and prevent the system from becoming overwhelmed.

Though most of us had not thought much about this kind of curve before, let alone the models underlying it, there is little new here for biostatisticians and epidemiologists. Research a century ago by Lowell J. Reed and Wade Hampton Frost at the Johns Hopkins University School of Hygiene and Public Health led to an epidemic model with parameters t (time), C_t (cases at time t), S_t (susceptible individuals at time t), and p (the probability of

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1. Julian Havil, *Curves for the Mathematically Curious: An Anthology of the Unpredictable, Historical, Beautiful and Romantic* (Princeton, NJ: Princeton University Press, 2019), xx.

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"adequate contact" for infection transmission between two specified individuals).[2] Their work was conducted largely in the 1920s but remained little known until popularized after World War II by their colleagues. Mathematically, it was not a particularly demanding exercise to assign initial values and then estimate C_{t+1} and S_{t+1} until the time when no cases remained. The resulting graphs also set cases against time, showing a rapid increase, a single peak to the curve, and then a decrease over time.

Reed and Frost were themselves building on decades of effort to use mathematics to make epidemics more comprehensible and predictable. The most important target of epidemiology models, at least since the seventeenth century, had been smallpox. In the nineteenth century, British statistician William Farr used models of smallpox outbreaks to explicitly link rates of infections to strains on medical systems at different times in an epidemic wave. In a series of papers, he tried to estimate the curves of mortality and recovery for a range of epidemic threats, and used them to make predictions about how many beds would be taken up by the stricken at London's Small-pox Hospital, for example.[3]

The current resurgence of interest in epidemic curves certainly draws on these efforts to understand epidemics mathematically. But more importantly, it is also indicative of two lessons historians of mathematics and statistics have emphasized about the persistent role of numbers in public policy. First, mathematical models do not ensure "rational" policy making. The incorporation of biomedical data into a model may seem to shift matters to objective or technocratic grounds, but data themselves are never value-neutral. Who (and what) is counted remain inherently contested.[4] Not to mention that absence of

2. Helen Abbey, "An Examination of the Reed-Frost Theory of Epidemics," *Human Biology* 24/3 (Sep 1952): 201–33.

3. Michael Donnelly, "William Farr and Quantification in Nineteenth-Century English Public Health," in *Body Counts: Medical Quantification in Historical and Sociological Perspective*, ed. Gérard Jorland, Annick Opinel, and George Weisz (Montreal: McGill-Queen's University Press, 2005), 251–65.

4. There is a substantial and rapidly growing literature showing how statistical measures are never "neutral" descriptions of the world. For a sense of the range of the recent work on biometrics and biostatistics in particular, see Vincanne Adams, ed., *Metrics: What Counts in Global Health* (Durham, NC: Duke University Press, 2016); Dan Bouk, *How Our Days Became Numbered: Risk and the Rise of the Statistical Individual* (Chicago: University of Chicago Press, 2015); Coreen McGuire, "'X-rays don't tell lies': The Medical Research Council and the measurement of respiratory disability, 1936–1945," *The British Journal for the History of Science* 52/3 (2019): 447–65; Thurka Sangaramoorthy and Adia Benton, "Enumeration, Identity, and Health," *Medical Anthropology* 31/4 (2012): 287–91; and Jacqueline Wernimont, *Numbered Lives: Life and Death in Quantum Media* (Cambridge, MA: MIT Press, 2019).

evidence is never evidence of absence, whether in relation to the number of daily tests administered or the racial disparities within cases.

Second, numbers can distract from what is actually important. After all, it's not the shape of the curve that matters to most people during a deadly epidemic. It's the area underneath it: the sum total of infections, hospitalizations, and inevitably with this disease, deaths. As our vague memories of integral calculus may remind us, even the flattest curve of new infections implies an ever-increasing total caseload. Moreover, in the United States, the undeniable success in "flattening the curve" in the spring never translated into sustained low rates of infection. Flattened curves can rise again. Past performance, in epidemiology no less than finance, is not indicative of future results. By promoting curve-flattening without acknowledging it as just a first step, political leaders may have inadvertently sapped public will to sustain mitigation over the long haul.

Mathematical models and graphical curves remain crucial tools for public health officials and the policy makers that they advise. But widespread trust in numbers—or in this case, in the curve—goes only so far in changing behavior. In an important sense, emphasizing the curve may have been counterproductive. A curve is, at heart, an abstraction: an infinite number of points, a collection of infinitesimal line segments. And the last thing public health officials want is for people to treat a deadly disease as an abstraction.