



MOORE'S CURSE



IN 1965, THE YEAR IN WHICH THE NUMBER OF components on a microchip had doubled, Gordon Moore predicted that “certainly over the short term this rate can be expected to continue.” In 1975 he revised the doubling rate to two years; later, it settled down at about 18 months, or an exponential growth rate of 46 percent a year. This is Moore’s Law. • As components have gotten smaller, denser, faster, and cheaper, they have increased the power and cut the costs of many products and services, notably computers and digital cameras but also light-emitting diodes and photovoltaic cells. The result has been a revolution in electronics, lighting, and photovoltaics. • But the revolution has been both a blessing and a curse, for it has had the unintended effect of raising expectations for technical progress. We are assured that rapid progress will soon bring self-driving electric cars, hypersonic airplanes, individually tailored cancer cures, and instant three-dimensional printing of hearts and kidneys. We are even told it will pave the world’s transition from fossil fuels to renewable energies. • But the doubling time for transistor density is no guide to technical progress generally. Modern life depends on many processes that improve rather slowly, not least the production of food and energy and the transportation of people and goods. There is no shortage of historical data to illustrate this reality, and I have calculated representative rates for the decades coinciding with the development of transistors (the first commercial application was in hearing aids in 1952) and microprocessors, as well as the rates for the entire 20th century, or even longer.

Corn, America’s leading crop, has seen its average yields rising by 2 percent a year since 1950. The efficiency with which steam turbogenerators convert thermal power to electricity generation rose annually by about 1.5 percent during the 20th century; if you instead compare the steam turbogenerators of 1900 with the combined-cycle power plants of 2000 (which mate gas turbines to steam boilers), that annual rate increases to 1.8 percent. Advances in lighting have been more impressive than in any other sector of electricity conversion, but between 1881 and 2014 light efficacy (lumens per watt) rose by just 2.6 percent a year, for indoor lights, and by 3.1 percent for outdoor lighting (topped by the best low-pressure sodium lamps).

The speed of intercontinental travel rose from about 35 kilometers per hour for large ocean liners in 1900 to 885 km/h for the Boeing 707 in 1958, an average rise of 5.6 percent a year. But that speed has remained essentially constant ever since—the Boeing 787 cruises just a few percent faster than the 707. Between 1973 and 2014, the fuel-conversion efficiency of new U.S. passenger cars (even after excluding monstrous SUVs and pickups) rose at an annual rate of just 2.5 percent, from 13.5 to 37 miles per gallon (that’s from 17.4 liters per 100 kilometers to 6.4 L/100 km). And finally, the energy cost of steel (coke, natural gas, electricity), our civilization’s most essential metal, was reduced from about 50 gigajoules to less than 20 per metric ton between 1950 and 2010—that is, an annual rate of about -1.7 percent.

Energy, material, and transportation fundamentals that enable the functioning of modern civilization and that circumscribe its scope of action are improving steadily but slowly. Gains in performance range mostly from 1.5 to 3 percent a year, as do the declines in cost. Outside the microchip-dominated world, innovation simply does not obey Moore’s Law, proceeding at rates that are lower by an order of magnitude. ■