In 1662, a London cloth merchant made several ingenious social comparisons that centuries later are considered the seeds of a science of quantitative observation. John Graunt’s use of mathematics was not what we would call sophisticated; in fact, he described it as the “Mathematiques of my Shop-Arithmetique” (Graunt [1662] 1975, 7). Graunt’s mercantile analytical tools included comparison by division in the forms of ratios and percents, comparison by subtraction over time to follow increases and decreases, and the use of relative time frameworks to search for and predict seasonal and cyclical patterns. These arithmetic tools, socially distributed by merchants, became the basis for algorithms used in inductive studies from the seventeenth century onward. Although the data Graunt worked with were time series spanning twenty years, his chief arithmetic tool, the Rule of Three or the Merchant’s Rule, is not usually associated with time series analysis. This comparison by division, however, is at the core of several types of data manipulation used in statistics, and I use it in this chapter to contrast the different contexts of quantitative reasoning.

The development from monetary to political to scientific arithmetic is the structure for this and all other chapters in Part I. We begin with an examination of Graunt’s adaptation of his shop arithmetic into a policy tool applied to the bills of mortality. I then explore the leveling qualities of seventeenth-century urban labor markets and epidemics and their impact on political and statistical notions of population. In the last section of the chapter, I examine Karl Pearson’s appropriation of Graunt’s techniques and subject for his own scientific investigation into the age distribution of deaths.
The main tool of Graunt's mercantile-turned-political arithmetic was the Rule of Three. The Rule of Three is the simple arithmetical technique of using three knowns to solve for a fourth unknown factor in a ratio relationship. For example, solving for c in the expression
\[ \frac{a}{b} = \frac{c}{d} \Rightarrow ad = bc. \]

Graunt, for example, noted that from 1628 to 1662, 139,782 males and 130,866 females were christened. Using the Rule of Three, he simplified the ratio relationship with the assertion that the value of the ratio served as proof that legislation against polygamy was consistent with the "Law of Nature" (Graunt [1662] 1975, 57–58).

In his book on *Painting and Experience in Fifteenth-Century Italy*, Michael Baxandall asserts that for centuries the Rule of Three was the most esteemed mathematical technique in Europe. Swetz sees the Rule of Three as essential for all societies in which trade and exchange flourished. Although it can be traced to mathematical works from India and China as early as A.D. 250, its popularity and importance in Europe were due to its use in commercial practice, and it was often called the "Merchant's Rule" or the "Merchant's Key." The earliest known printed mathematics books in the West were from late fifteenth-century Italy. These were texts for those engaged in commercial reckoning. The Rule of Three, *de regola del tre o de la regula de le tre cose*, was the primary mathematical technique in these early texts and almost all of the illustrations given for the Rule of Three were of a mercantile nature.

In his book *Reckoning with the Merchant's Rule* (1649–1658), Charles II needed to reconstruct the crown's authority following a civil war, the beheading of Charles I and Oliver Cromwell's rule. The commercial patron commanded art that visually played on the skills of comparing ratios and comparing volumes. Two centuries later, the merchant Graunt was flaunting his prowess with this rule and trying to persuade king and counselors of its effectiveness in simplifying comparisons of awkward quantities.

Although its popular origins were in commerce, the Merchant's Rule eventually became an important tool in the science of observation. Karl Pearson and Udny Yule, unlike John Graunt, were undoubtedly linked in their formal education and their research programs to the realm of science, mathematics, and statistical theory. One of the important vehicles for publishing their statistical research was the journal *Biometrika*. In a 1901 letter to Pearson, Yule suggested a quotation from Charles Darwin on quantitative methods as a motto for the new journal. Pearson agreed and used this passage, from Darwin's letter of May 23, 1855, in the first editorial of *Biometrika*: "I have no faith in anything short of actual measurement and the Rule of Three" (Darwin 1911. 411; Yule 1901b; Pearson 1901a, 4). The Rule of Three was the primary instrument of analysis in Graunt's seventeenth-century political arithmetic on the bills of mortality. By the nineteenth century, Darwin was far from alone in relying almost totally on the Rule of Three for quantitative analysis of observed natural and social phenomena.

The authors of the fifteenth-century Italian arithmetic books often used examples of the selling of cloth to illustrate the Rule of Three. It should, therefore, come as no surprise that a draper was to make the link between monetary and political arithmetic and introduce the Rule of Three to Charles II and his advisers for the purposes of quantitative decision making in public policy. In 1662, John Graunt's exhaustive and ingenious use of his "Shop-Arithmetique" ensured the unusual appointment of a cloth merchant to the newly formed Royal Society. In his history of the Royal Society, Thomas Sprat used Graunt's appointment as an example of the king's, and thus the Royal Society's, "great regard for the "manual Arts" and "Mechanic Arts." In appointing Graunt as a charter member of the Royal Society, Charles II, according to Sprat, "gave this particular charge to His society, that if they found any more such Tradesmen, they should admit them all, without any more ado" (Sprat 1667, 67). It is no accident that the first foot in the door for the social sciences was that of a haberdasher.

### Political Arithmetic with the Rule of Three

Why were the methods and conclusions of this merchant so well received by Charles II, his Privy Council, and the newly chartered Royal Society? In an essay on objectivity and authority, Ted Porter illustrated how statistics, in the realm of public policy, were used more to justify and rationalize than to discover and understand. Hereditary rulers who had absolute, unquestionable authority had no need for statistics (Porter 1991, 252). When Graunt presented his observations, the British royal family had only just come back into power following a civil war, the beheading of Charles I and Oliver Cromwell's rule (1649–1658). Charles II needed to reconstruct the crown's authority,
Reckoning with the Merchant’s Rule

Table 2.1 Graunt’s table of annual burials and christenings in London from 1604 to 1651. The first four columns of burials do not include deaths due to the plague, which are counted in the fifth data column. Graunt cautioned that from 1642 onward, the account of christenings was not an accurate recording of total births.

<table>
<thead>
<tr>
<th>Year</th>
<th>Births</th>
<th>Christenings</th>
<th>Burials</th>
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<tbody>
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<td>1604</td>
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Source: Graunt [1662] 1665, 174–175.

In the year 1592, and 1636 we find the proportion of those dying of the Plague in the whole to be near alike, that is about 10 to 23, or 11 to 25, or as about two to five.

In the year 1625, we find the Plague to bear unto the whole in proportion as 35 to 51 or 7 to 10, that is almost the triplicate of the former proportion for the Cube of 7, being 343, and the Cube of 10, being 1000, the said 343 is not 2/5 of 1000.

In Anno 1603, the proportion of the Plague to the whole was as 30 to 37, viz. as 4 to 5, which is yet greater than that last of 7 to 20. For if the Year 1625, had been as great a Plague-Year as 1603, there must have died not only 7 to 10, but 8 to 10, which in those great numbers makes a vast difference.

We must therefore conclude the Year 1603, to have been the greatest Plague-year of this age. (Graunt [1662] 1975, 45–46)
## Table 2.3

<table>
<thead>
<tr>
<th>Year</th>
<th>Abortive and Stillborn</th>
<th>Aged</th>
<th>Apoplexy and Paralysis</th>
<th>Aged</th>
<th>Blooded</th>
<th>Buried, and Sudden Florid</th>
<th>Cholera, and Puerperal Remittent</th>
<th>Coagulum, and Wind</th>
<th>Double and Trivial</th>
<th>Fistula, and Infants</th>
<th>Gastric Fistula, and Throat</th>
<th>Jaundice</th>
<th>Ophthalmia and Ear Inflammation</th>
<th>Scurvy and Rickets</th>
<th>Typhus and Typhoid</th>
<th>Venereal</th>
<th>Whist, and Scrofula</th>
<th>Other Causes of Death</th>
<th>Total</th>
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<td>1647</td>
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</tbody>
</table>

Note: The table shows the annual number of deaths in London by cause from 1647 to 1660. Given the "Incapacity of my sheet," Grunt limited his table to twenty years, omitting the years between 1636 and 1647 because "nothing extraordinary" happened in those years. In many of his calculations, Grunt used the twenty-year (1629-1635 and 1637-1642) period for burials, which is in the next to last column. Given the incapacity of my sheet, I omitted six columns of subtotals of annual groupings and aggregated twenty-five causes of death that resulted in less than sixty-five burials in twenty years into a row labeled "sum of the others." I also appended the last column that recalculates the row totals and illustrates some printing or calculation errors in Grunt's totals.

---

1. Based on Grunt's (1663) plans Grunt's use is proportional in the category of the table; on the proportion of numbers under a particular heading to the total of the table.

---

2. Table 2.3. Grunt's Table of Burials and christings by year for the Bahamas (from 1629-1660). The table shows that from 1629 to 1636, Grunt took a relatively flat year. 1636, because he calculated that year, the amount of deaths, for instance, was not influenza. Grunt also observed that, for example, 1637 was a year of death. He observed that, for example, 1637 was a year of death. He observed that, for example, 1637 was a year of death. He observed that, for example, 1637 was a year of death.
Reckoning with the Merchant's Rule

Table 2.4 Final forms of Graunt's comparison by division:

<table>
<thead>
<tr>
<th>Type</th>
<th>Numerical form</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of occurrence</td>
<td>c/d = 1/32</td>
<td>7 percent die of old age</td>
</tr>
<tr>
<td>Proportion</td>
<td>c/d = 1/50</td>
<td>4 percent die of old age</td>
</tr>
</tbody>
</table>

Graunt's investigation led to several interesting conclusions:

- The practice by English women of maintaining a straight, horizontal posture during childbirth resulted in a higher maternal death rate than in countries where this was not the fashion.
- Mental work, typical of businesses in London, produced "Anxieties of the minde," which hindered breeding compared with the "corporal Labour and Exercizes" of the country.
- Polygamy should not be allowed since the sex ratio at birth of males to females was greater than one, and where it is allowed "Wives can be no other then Servants."
- During the great plagues, one-fifth of the population of London died while two-fifths fled to the countryside; but the "City is fully re-peopled within two years." The plague that began in 1603 lasted eight years, the one that began in 1636, twelve years, but the plague of 1625 lasted only one year.
- Wars could easily be waged and colonies settled without destroying the due proportion of males to females.
- The population of England and Wales was 6,500,000, and the population of London represented one-fifteenth of the total.
- The population of London doubled in 70 years compared with 280 years in the country parishes.

Source: Graunt [1662] 1975, 72.
Graunt’s Epidemiology

The link between the shop arithmetic and the political arithmetic also comes out clearly in Graunt’s analysis of seasonal and annual variations. In addition to his extensive use of the Merchant’s Rule, Graunt employed comparison by subtraction, “medium” (average) annual values, and relative time frameworks to identify unhealthy years and seasons and to search for cyclical patterns in illness. For example, Graunt labeled a year as “sickly” if the number of burials in that year was greater than the numbers in the previous year and the subsequent year.

Graunt’s search for temporal patterns included a study of the progress of some diseases in absolute time. Graunt tried to determine whether rickets, a disease that appeared on the bills for the first time in 1634, was a new disease in that year was greater than the numbers in the previous year and the former was the case. He used the image of “backstarting” (what contemporary consumption theorists would call the “ratchet” effect) to visualize a typical temporal pattern of the annual progression in the mortality of a new disease such as rickets:

Now, such backstartings seem to be universal in all things; for we do not only see in the progressive motion of the wheels of Watches, and in the rowing of Boats, that there is a little starting, or jerking backwards after every step forwards, but also (if I am not much deceived) there appeared the like in the motion of the Moon, which in the long Telescope at Gresham-College one may sensibly discern. (Graunt [1662] 1975, 39)

Using a relative-time framework, Graunt determined that, “the unhealthful Season is the Autumn” (Graunt [1662] 1975, 51). This was particularly true during epidemics of bubonic plague. The number of plague deaths generally peaked in late August or September. If mortality could be tracked on a weekly basis, then a marked increase in deaths in late summer would signal a visitation of pestilence.

The emerging urban markets in seventeenth-century London, in addition to providing Graunt the analytical tools, called forth the data for his observations. Throughout the seventeenth century, every week, in every parish of London, state-appointed searchers visited the homes of the recently deceased to determine the cause of death. The searchers, older women by decree, reported their findings to the parish clerks, and every Thursday, the numbers of parish christenings and burials and the causes of death were published and sent to those who had paid four shillings per year for the bills of mortality (a portion of the annual bill of mortality for 1665 is reproduced in Table 2.5). The subscribers included merchants anxious about the future of their trade and the wealthy, who could afford to leave town at the first hint of pestilence.

Great Plagues

Graunt applied his “shop-arithmetic” to numbers gleaned from the searchers’ data, which had been tabulated on a weekly basis from as early as 1532. These parish bills, regularly posted to monitor the course of plagues, were products of a modern way of perceiving and accounting the human creatures that inhabited the British Isles. The bubonic plagues were miss phenomena; and visitations brought home the numerical equivalence of the dead, whether they were rich or poor while they lived. The breakdown of the sense of the individual was vividly described in Daniel Defoe’s account of the mass burial pits in which thousands of corpses were put during the 1665 London plague:

The Cart had in it sixteen or seventeen Bodies; some were wrap up in Linen Sheets, some in Rugs, some a little other than naked, or so loose, that what Covering they had fell from them in the shooting out of the Cart, and they fell quite naked among the rest; but the Matter was not much to them, or the Indecency much to any one else, seeing they were all dead, and were huddled together into the common Grave of mankind, as we may call it, for here no Difference made, but Poor and Rich went together, there was no other way of Burials. . . .

It was reported by way of Scandle upon the Buriens that if any Corpse was delivered to them decently wound up, as we call’d it, in a Winding Sheet, Ty’d over the Head and Feet, which some did, and which was generally of good Linnen; I say, it was reported, that the Buriens were so wicked as to strip them in the Cart and carry them quite naked to the Ground. (Defoe [1722] 1968, 69–70)

Thomas Dekker’s description of mass burial during the 1603 visitation in London is similar:

1 Charles Hollar (1839, 100–42) draws on many historical sources to try to determine the dates and forms of the various bills of mortality. The fire of 1666 apparently destroyed all sets of London Bills before 1658, but Graunt’s tables, John Bell’s London’s Remembrancer, and assorted manuscripts enable a reconstruction of some of the earlier years. The distinction of births and deaths by sex and the designation of cause of death were introduced in the London bills in 1639. Graunt therefore chose that year as the start of his data analysis. Following suggestions by Graunt and William Petty, the London bills eventually included number of marriages and age of death.

2 As one can see in Table 2.3, the leveling qualities of the London bills of mortality are also evident in the number of executions. For the year 1649, King Charles I and commoners are presumably added together to calculate the total of 29 deaths.

3 Although Defoe’s account was published in 1722 as an eyewitness account of a London saddler in 1665, historians doubt that Defoe was more than four years of age during that year of the plague. The narrative was supposedly based on a journal of H.E., which, as James Sutherland points out in his introduction to the Journal, are the initials of Daniel Defoe’s uncle. Unlike in his other works, Defoe makes extensive use of data and documentation in The Journal, and it is very possible that Graunt’s observations (from later editions) or John Bell’s London’s Remembrancer was one among the sources Defoe used.
Table 2.5 A portion of a London bill of mortality for the plague year of 1665. This was a year-end bill that totaled deaths by cause for the entire year. Not included in this reproduction are the total deaths by Parish.

1665.

A General BILL for this present Year,

Ending the 19th Day of December. 1665.

According to the Report made to the King's most excellent Majesty,

By the Company of Parish Clerks of London, &c.

DISEASES AND CASUALTIES.

A Boresv and Stillborn 617
Aged 1564
Ages and Fever 1535
Appenlisy and Suddenltly 116
Beilk 10
Bilious 10
Bloody Flux, Soreness, and Flux 185
Bust and Scalded 2
Cancer, Carcinom, and ? 57
Canker and Thrush 111
Childbed 617
Cholera, and Infant 125
Cold and Cough 66
Colic and Wind 121
Consumption and Tiphthick 486
Diphtheria 12
Dysentery and Typhus 147
Drowned 50

Executed 11
Exposed 11
Ovreal and Starved 45
Palsy 19
Poli 10
Pox 485
Prognosis 15
Quinsey 15
Rickets 40
Ruling of the Lights 57
Rupture 127
Scarify 5
Shingles and Swine Pox 2
Sore, Ulcers, Breaked, 1
Stomach and Infants 125
Superstitious Spleen and Gangrene 128
Swolled 8
Swolled, with the Guts 128
Sufficient 12
Suffocation and Typhus 48
Sweat 7
Teeth and Worms 261

A Collection of the Yearly Bills of Mortality from 1657 to 1758 Inclusive [1758] 1759.

Source: A Collection of the Yearly Bills of Mortality from 1657 to 1758 Inclusive [1758] 1759.

Plate: A portion of a London bill of mortality for the plague year of 1665. This was a year-end bill that totaled deaths by cause for the entire year. Not included in this reproduction are the total deaths by Parish.

1665.

A General BILL for this present Year,

Ending the 19th Day of December 1665.

According to the Report made to the King's most excellent Majesty,

By the Company of Parish Clerks of London, &c.

DISEASES AND CASUALTIES.

A Burse and Stillborn 617
Aged 1564
Ages and Fever 1535
Appendectomy and Suddenlty 116
Beilk 10
Bilious 10
Bloody Flux, Soreness, and Flux 185
Bust and Scalded 2
Cancer, Carcinom, and ? 57
Canker and Thrush 111
Childbed 617
Cholera, and Infant 125
Cold and Cough 66
Colic and Wind 121
Consumption and Tiphthick 486
Diphtheria 12
Dysentery and Typhus 147
Drowned 50

Executed 11
Exposed 11
Ovreal and Starved 45
Palsy 19
Poli 10
Pox 485
Prognosis 15
Quinsey 15
Rickets 40
Ruling of the Lights 57
Rupture 127
Scarify 5
Shingles and Swine Pox 2
Sore, Ulcers, Breaked, 1
Stomach and Infants 125
Superstitious Spleen and Gangrene 128
Swolled 8
Swolled, with the Guts 128
Sufficient 12
Suffocation and Typhus 48
Sweat 7
Teeth and Worms 261

Plague epidemics definitely qualify for the label of mass phenomena, and the weekly mortality during plague years was structured through time in a symmetrical, formal pattern. Graunt and his contemporaries saw this pattern in comparisons of weekly mortality tables. In all major and minor plague years in London in the seventeenth century the peak mortality was in the last weeks of August and the first weeks of September. Linked with the seasonal pattern, there was also a change in the typical symptoms of the disease during the course of an epidemic. The changing severity of the symptoms was one of the determining causes of the seasonal symmetry in the mortality curve. The symptoms at the prime of the life of the visitation were very different from those experienced at the birth and death of the epidemic. Creighton quotes William Boghurst, an apothecary who treated hundreds of cases of the plague in 1665:

It fell not very thick upon old people till about the middle or slack of the disease, and most in the decreases and declining of the disease. . . . In summer about one-half that were sick, died; but towards winter, three of four lived. (Boghurst quoted in Creighton [1891] 1965, 675)

Defoe also remarked on the change of the rate of mortality of those infected:

few people that were touch'd with it in its height about August and September, escap'd; And, which is very particular, contrary to its ordinary Operation in June and July, and the beginning of August, when, as I have observ'd many were infected, and continued so many Days, and then went off, after having had the Poison in the Blood a long time, but not on the contrary, most of the People who were taken during the two last Weeks in August, and in the three first Weeks in September, generally died in two or three Days at farthest, and many the very same Day they were taken. (Defoe[1722] 1968. 191–192).

Indeed, Defoe mentions rumors of a specific turning point in the mortality: the peak was apparently one September morning when 3,000 died in London between the hours of one and three o'clock in the morning.

An indication that the disease had lost its fatal strength was when the swellings (the buboes) in the lymph nodes discharged pus (suppurated). This was much more common in those who were smitten after the early autumn peak of the epidemic. Hardened buboes characterized the more fatal form of the disease that was common around the August–September peak. Creighton did not publish graphs of seasonal variation in his nineteenth-century study of the history of epidemics in Britain, but his description of the temporal change in the bubonic symptoms evokes a visual image of the seasonal
Weekly Variation in London Burials
Major Plague Years, June-Dec. 1603, 1625, 1636, 1665

Figure 2.1 This plot is based on the fifth edition of Graunt's Observations (1662, 1676, 1899). The height of a horizontal line measures the number of deaths for that week averaged over four plague years.

epidemic "curve" or "law" that must have entered into the minds of those like Creighton and Graunt who constructed tables of the weekly deaths from the bills of mortality:

an epidemic of plague declined as a whole in malignity towards the end, so that the buboes suppurated, and three out of four, or three out of five, patients recovered. If that were the case in the descent of the curve, why should there not have been something corresponding in the ascent? (Creighton 1891, 1965, 655)

Graunt in the seventeenth century, Defoe in the eighteenth century, and even Creighton in the nineteenth century worked with tables to get a sense of the process of plague mortality. I have taken the liberty of using some of the raw material Graunt worked with to construct graphs that will give those of us less attuned to tabular reasoning a sense of the temporal patterns of epidemics of bubonic plague.

If one plots typical seasonal variation of deaths per week in seventeenth-century London during plague years, one constructs a bell curve with a peak in mortality in early autumn (see Figures 2.1, 2.2). There is no similar periodic pattern to the appearance of plagues in London that would enable one to predict which year would be a plague year. Once a plague arrived, however, it took on an incredible weekly...
pattern in late August: first exponential growth, a turning point, then rapid decline. The parish clerks, responding to decrees by the lord mayor and financed by the merchants and the rich, tracked the mortality pattern week to week for the fire of London in 1666, but from data in Graunt's fifth edition of The Parish Clerk's Remembrancer (1676), Bell's London's Remembrancer (1665), W. Heberden (1801) 1973, and manuscripts that Hull (1899, 426-428) investigated, it is possible to construct graphs of seasonal variation. The graphs used in Figures 2.1-2.4 group weekly (in the case of Figure 2.1) or monthly data (in the case of Figures 2.2-2.4) in a relative time framework of an annual cycle. For Figure 2.1, the last week in December; for Figures 2.2-2.4, the months go from January to December.

What follows is a description of Figure 2.1, but a substitution of the word "month" for "week" will adapt the description to the other three figures. The vertical axis measures deaths per week in London parishes. The height of the horizontal line for each week measures the number of deaths for that week averaged over the four great plague years. The height of the end of a vertical line perpendicular to a horizontal line plots the number of deaths in that week for a specific year, and the length and direction of the vertical line indicates each year's deviation from the average for that week.

Figure 2.1 illustrates the weekly variation in total deaths for the years of major plague visitations in London, 1603, 1625, 1636, 1665. One can see the peak of average mortality in the fourteenth week after the beginning of June, which would be the last week in August or first week in September. The average number of deaths for the four great plague years for that week was 4,000. One can see by the upward reaching vertical lines on the far right of each horizontal bar that the deaths in 1665 were above average for almost every week and greater than any of the preceding years. In the first week in September 1665, parish clerks in London recorded 8,252 deaths.

Even for minor plague years in the seventeenth century, in which total annual plague deaths were 3,000 or less, and in which diseases such as typhus (spotted fever) claimed more lives, the remarkable seasonal pattern persists.3 Figure 2.2 plots the variation in deaths per month over an entire year for the years of relatively minor pestilence from 1640 to 1646. The symmetrical pattern centered around a peak of deaths in September is not evident in the monthly variation plotted from the bills of mortality recording deaths from 1597 to 1600 (Figure 2.3). Likewise the seasonal pattern of mortality for 1764-1767 (Figure 2.4), with declining deaths as the summer proceeds and a peak of monthly mortality in early winter, is remarkably different from that in the preceding two centuries.4 The weekly, numerical tracking of the ascent and descent of the curve and the sudden, indiscriminate elimination of over a sixth of the urban population no doubt helped to lay the seeds for a statistical way of thinking. In seventeenth-century London, a person could be just a corpse and a corpse could be a number. As Graunt illustrated, the numbers could be manipulated to quantify population and the rate of change in population. The acknowledgment of equivalence and the summation of many individuals led to a recognition of social mass phenomena. The whole was different from the sum of the parts and displayed a stability and certainty in stark contrast to the attributes of individual constituents. Populations could thus be characterized by summary parameters and analytical images.

Population

The significance to statistical theory of Graunt's observations on the bills of mortality stems from three important insights: the applicability of mercantile arithmetic to a social and political science of observation; the importance of numerical tracking to statistical theory; the recognition of equivalence in a population of many individuals. The whole was different from the sum of the parts and displayed a stability and certainty in stark contrast to the attributes of individual constituents. Populations could thus be characterized by summary parameters and analytical images.

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3 There were more people living in London in 1665 compared with the other years, but even the proportionate mortality appears to be higher in 1665. Based on estimates of London population by Charles Coghston (1891) 1965, 660 and the number of deaths recorded in the bills of mortality, 17 percent of the population died in 1665, 16 percent died in 1625, and 21 percent died in 1665.

4 The high summer mortality in the seventeenth century might have been as much a background cause of the relatively high frequency of bubonic plague epidemics as an effect of the epidemics.
population to the state; and the stability of social proportions and ratios over time and across parishes. Population is a key concept in the logic of statistical binding the constituents, and of a manifestation of the whole. The historical context in which these assumptions were first relevant to nation-states is also the context in which statistics had its origins.

Equivalence of all inhabitants, like equivalence of outcomes in a game of chance, is a relatively modern notion. For example, Karl Marx in volume one of *Capital* argued that Aristotle failed to fully understand the economic relationship of value in exchange because his ideas were the product of a slave society where equivalence between laborers had no meaning (Marx [1867] 1976, 152). Rigid social inequality bound to a system of prohibitions of equivalent exchange values, and of population in feudal as well as slave societies.

Geoffrey Kay and J. Mott (1982) argue that, in Britain at least, the feudal order was replaced by the order of equivalence, which gave rise to the notion of population. Kay and Mott point out that the Doomey Book of the eighteenth century did not count people, but instead, listed fiscal units to which groups of property rather than the number of people. The counting of John Graunt and William Petty six centuries later assumed political and fiscal equivalence of citizens and their labor as a source of value.

By the seventeenth century, commodity exchange in London was becoming what Marx would describe as a "very Eden of the innate rights of man" (Marx [1867] 1976, 280). The sphere of circulation of commodities between people appeared to be an exclusive realm of freedom and equality, and within this sphere what was counted was not the specific nature of concrete labor, but the abstract labor time embodied in goods produced for exchange. With the market's reduction of the essence of all value to human labor in the abstract, and with the political creation of an "order of equivalence," a population way of thinking became a necessary part of the state. Schumpeter described this dawn of the era of equivalence: "A numerous and increasing population was the most important symptom of wealth, it was the chief cause of wealth; it was wealth itself - the greatest asset for any nation to have. Utterances of this kind were so numerous as to render quotations superfluous" (Schumpeter 1954, 251).

In his observations on the bills of mortality, Graunt noted that "Princes are not only Powerfull but Rich, according to the number of their People (Hands being the Father, as Lands are the Mother, and Womb of Wealth)" (Graunt [1662] 1975, 61). Eighteenth-century philosophers considered population one of the most important social issues, and by the end of the nineteenth century the concept of population was an integral part of statistical theory. John Graunt's observations inspired Johann Peter Sussmilch's work on population. That in turn inspired Thomas Malthus, and the latter was a source of inspiration to Charles Darwin.

The "Divine Order" that became Susmilch's theme was initiated in Graunt's revelation of the stability of the ratios he calculated. Graunt's declaration of stability, in phenomena as diverse as the ratio of male to female births or the proportion of accidental deaths to total deaths, meshed well with the goal of the scholars of the Enlightenment to find uniformity amid variety and order amid chaos.

Graunt's Statistical Structure in Time: The Life Table

Graunt's confidence in the stability of the ratios that he had constructed spanning twenty years of data is evident in his construction of the first life table. This statistical structure in relative time is now a staple in actuarial practice. The relative time is the human life cycle marked by decades of age. Examining the numbers dying by each cause over twenty years, Graunt estimated how many deaths were those of infants, and how many were elderly. For these decades of the life cycle and the ones interpolated in between, Graunt determined out of 100 live births how many died at each decade, and therefore what percentage was alive above each age. Graunt calculated that in twenty years 71,124 people, out of a total death count of 229,250, died of causes that he surmised affected only children. His next step was to use the Merchant's Rule to put this into a proportional form that readers could easily grasp: "that is to say, that about 1/3 of the whole number could be expected to die in that age." Of the 100,000 people left, 10,000 of these died of those diseases, which we guess did not light upon children under four or five Years old" (Graunt [1662] 1975, 29–30). Graunt guessed that one-half of deaths due to certain other causes (e.g., small-pox) were also children under six and concluded that "three sixty per cent of all quick conceptions, died before six years old" (Graunt [1662] 1975, 30).

Graunt estimated that in 15 of all deaths, 7 percent, were attributed to old age by the searchers, and concluded that "in any other Country more

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For example, in the course of explaining the "science of means" in his article on the "Method of Statistics" in the *Jubilee Volume of the Royal Statistical Society*, Sidney Edgeworth commented, "The term 'Means' of course implies the correlative conception: members of a class, or terms of a 'Series' (in Mr. Venn's phrase) of which the mean is to be taken: 'Maeusen-Schnitten' in the language of Professor Lesch" (Edgeworth 1865, 122).

In Marx's words: "However, Aristotle himself was unable to extract this fact, that, in the form of commodity-values, all labour is expressed as equal human labour and therefore as labour of equal quality, by inspection from the form of value, because Greek society was founded on the labour of slaves, for which not its activity but the inequality of use of and of their labour-power. The secret of the expression of value, namely the equality and equivalence of all kinds of labour because and so far as they are human labour in general could not be deciphered until the concept of human essence had already acquired the permanence of a fixed popular opinion" (Marx [1867] 1976, 131–132).

William Petty not only equated one person to another but even land and people through calculation of the monetary value of land. In *Reckoning with the Merchant's Rule* (Graunt [1662] 1975, 61), Graunt declared that the "Rule of Three" was an act of commerce and percent was an act of finance. If money had been borrowed or lent then the phrase "per cent" or "per centum" was in the vocabulary. "Per cent" was a type of proportion, an offering of the 'Rule of Three'; it was a statement of the rate of interest (for word origins see the *Oxford English Dictionary*, 2nd ed., 1989, vol. 11, 1031). It was in the life-table construction, when he wanted a common denominator for each decade of life, that Graunt reduced proportions to percents. Although Graunt used first differences and expressed some proportions in the form of percents, he never combined the comparison by subtraction with comparison by division in a
Table 2.6 The first life table, constructed by John Graunt.

\[\text{Viz. Of an hundred there dies within the first five years \-----36} \]
\[\text{The fourth--6} \]
\[\text{The next ten years, The next--4} \]
\[\text{or Decad--24} \]
\[\text{The second Decad--15} \]

Source: Graunt [1662] 1665, 125.

then seven of the 100 live beyond 70, such Country is to be esteemed more healthfull then this of our City" (Graunt [1662] 1775, 38). Graunt interpolated percents between the extremes of infancy and old age and crudely estimated the number of deaths for each decade of life for a cohort of 100 live births.37 Graunt's life table is reproduced in Table 2.6. True to his aim of political arithmetic, Graunt's first use of the life table was to estimate the number of fighting men from London the king could rely on for future wars. From his table, Graunt calculated that 34 percent of all males were between the ages of sixteen and fifty-six; he translated that into approximately 70,000 men of fighting age in London proper.

In a footnote in his 1899 edited version of Graunt's observations, Charles Hull lists Edouard Mallet's estimates of relative frequency of death by age based on recordings of age of death in Geneva from 1601 to 1700. Mallet's data showed 42.6 percent of all deaths were of those aged six or less, and 5.8 percent of those who died were over seventy-six years of age. Neither Graunt nor Mallet constructed graphs from their tables, but Figure 2.5 graphically compares Graunt's estimates of the relative frequency of age of death to those of Mallet's. The former, being an arithmetical interpolation between the two end-point ages, is obviously a smoother graduation, but the images are similar.

Graunt's work inspired not only the construction of life tables (e.g., by Edmund Halley), but also the inclusion of age of death in the London bills of mortality. In 1758, Corbyn Morris summarized death by age based on the London bills for various years in the eighteenth century. Figure 2.6 illustrates the stark contrast between the age distribution of deaths in London in 1728-30 and in the United States in 1991.38 What is striking in the plots of Graunt's, calculation of a percent change. Percent change, as opposed to just percent, was not a common monetary algorithm until the nineteenth century. When Graunt examined growth or change over time he used expressions such as "doubled" or "increased from one to four."

37 Karl Pearson (1978) and Anders Hald (1990), among others, discuss Graunt's interpolation in the construction of a life table.

38 With both Figures 2.5 and 2.6, one must keep in mind that the age distribution of the population influences the age distribution of deaths and vice versa.
Mallet's, and Morris's data is the high level of child mortality. Even in the U.S. data, the first few years of life appear more precarious than those that immediately follow.

Graunt's observations on the bills of mortality earned him membership in the Royal Society and posthumous fame as the "father of statistics." Graunt's original contribution to the construction of life tables is well recognized as is his observation that year after year, parish after parish, there were more males born than females (Graunt reduced the ratio for London to fourteen males to every thirteen females). Even his observation that "Physicians have two Women Patients to one Man, and yet more Men die than Women" (Graunt [1662] 1975, 12) is still referred to in the popular press of the late twentieth century.

Karl Pearson and others have seen Graunt's main contribution to statistics as the implicit recognition of the stability of statistical ratios over time and space (Pearson 1978, 30). For example, Graunt noted with "Chronical" diseases, such as consumption (tuberculosis), suicide, and even in the case of some types of accidents, such as drowning, over the years the deaths due to particular casualities bore a constant proportion to the whole numbers of burials.

Although Graunt's contribution in the area of statistical ratios is well recognized, far less attention has been paid to the link between Graunt's arithmetic and his occupation. Only a merchant would have analyzed the data from the bills of mortality in the way that Graunt did, and it was merchants, anxious to predict the future course of their trade, who paid the four shillings for the results of the work of the searchers and parish clerks on the bills of mortality. Also, out of past experience or wishful thinking, merchants had confidence in the overall stability of the numbers they worked with through thick and thin markets. Graunt not only demonstrated the stability of ratios, but he also hoped that his analysis would lead to even greater commercial and social stability. He argued that careful quantification of "the People" would engender "the knowledge wherof Trade, and Government may be made more certain,

In their reckoning of the chance of death, nineteenth-century Mallet's, and Morris's data is the high level of child mortality. Even in the U.S. data, the first few years of life appear more precarious than those that immediately follow.

Graunt was a retailer and his shop arithmetic consisted of using comparison by division to simplify relationships, using comparison by subtraction to determine the temporal patterns of illness and mortality, calculating "mediums" (averages) over time to eliminate irregularities, presenting the data in the form of spread-sheet-style tables, and reorganizing the values into relative time frameworks for comparisons between seasons and between ages. In adapting his shop arithmetic to political arithmetic, Graunt expanded the time horizon, addressed issues of policy, and used his analytical tools to persuade and justify. In their reckoning of the chance of death, nineteenth-century

While replicating Graunt's work, I realized that the obvious choice of software was not a statistical package, but rather a spreadsheet program, which is more associated with financiers and retailers than with scientists or econometricians. The formulas commonly used with spreadsheet software are very similar to Graunt's shop arithmetic. I also noticed in my spreadsheet replication that Graunt had made several errors, some quite significant, in his arithmetic.

46 Statistical Visions in Time

Scientists and applied mathematicians built on the monetary and political layers, but embellished the storytelling with symbols embedded in equations and laws embodied in smoothed curves. Karl Pearson's work on the age distribution of the chance of death serves as an excellent illustration of how the shop-cum-political arithmetic of Graunt was modified for the purposes of scientific investigation and the development of a mathematical theory of statistics.

Pearson's Statistical Structures in Time: Mortality Curves

To the Royal Society

which fostered the many lines of inquiry set in train by John Graunt through his 1662 publication, Natural and Political Observations on the London Bills of Mortality.

Thus read the dedication of Egon Pearson's edition of his father's lectures on the history of statistics (Pearson 1978). Karl Pearson was one of many Royal Society fellows who was inspired by Graunt's political (shop) arithmetic, and Graunt was one of the major actors in Pearson's history.

In his essay "The Chances of Death," Pearson addressed a question similar to that of Graunt's: Out of a cohort of 1,000 people born alive at the same time, how many die at each age? In contrast to the table that Graunt constructed, Pearson answered with a mortality curve (Figure 2.7). The graph included the frequency of death by age plotted from data collected from 1871 to 1880 by the registrar-general. Pearson decomposed the curve connecting the data points into five smooth curves mapped out from mathematical functions of chance frequency distributions centered on the ages of 72, 42, 23, and 3 years and 1 month before birth.

Pearson's essay was an argument for adopting a modern, more mature notion of chance and death. The medieval notion of chance was that of chaotic, random incident; the modern notion of chance was that of mathematical law and geometric order. Similarly, the medieval metaphor of death was the random action of the "dance of death." In contrast with the medieval image of the dance of death, Pearson saw death as "a marksman with a certain skewness of aim and a certain precision of weapon" (Pearson 1897, 25). To metaphorically explain his decomposition of a mortality curve into five chance distributions, Pearson had his wife paint his stochastic view of the chances of death as that of five marksmen of death aiming their deadly weapons at humans traveling over the bridge of life (Figure 2.8). To compare his view of death — that is, a regiment of marksmen maintaining law and order in mass

46 Statistical Visions in Time

In London in 1634, the state took over from the church the regular publication of mortality data. The image of the "dance of death" may have had a more orderly, deterministic flavor in the Middle Ages than Pearson gives credit for. Historian Mary Hill Cole pointed out to me that medieval dances were often very defined, formal, and scripted rituals.

In his essay Pearson mentions that he had asked two artists to draw his image of the bridge of life. The one trained in "the modern impressionist school" failed, but his wife "resolved among the creations of Hofmann, Heumann, and Blake" came closer to realizing his image. Karl Pearson's rough sketch and Maria Sharpe Pearson's prints and large painting of the bridge of life are in the Pearson Papers at The Library, University College, London.
Figure 2.7 Pearson's plot of the age distribution of death in England 1871–1880 (curve with x's), broken down into five component chance distributions. Source: Pearson 1897, plate IV.

Figure 2.8 Maria Sharpe Pearson's etching of the Bridge of Life. Each marksman represents a component curve on Figure 2.7. Source: Pearson 1897, frontispiece.
phenomena — with the medieval image. Pearson reproduced examples of the older notion of the "dance of death." These reproductions included fifteenth-century images from a cemetery in Gross-Basel (Figure 2.9) and sixteenth-century prints of Holbein.

Pearson's marksmen aimed their weapons at the mode years of the five frequency distributions. The type of weapon gave a sense of the maximum mortality in the mode year and the standard deviation of the distribution. For example, the weapon of the mortality of childhood was centered on the third year of life, more people died at this mode than at the mode of youth or middle-age mortality, and the standard deviation of childhood mortality was less than any other except that of infancy. The precision and deadliness of the marksmen's gun was thus conveyed with the weapon of a "maxim gun." In middle-age mortality, centered on the forty-second year of life, the fire of the marksmen is "slow and scattered, and his curve of destruction a very flat-topped one. His work might be typified by a blunderbus as compared with the rifle-fire of old age death" (Pearson 1897, 31).

It is obvious from the overlapping component frequency curves in Figure 2.7 that a person dying at age fifteen could have been struck by either the marksmen of childhood, middle age, or youth, though most likely that of youth. Pearson did not fully explain how this translated into reality, but he linked the five distributions to different causes. He plotted the age distribution for cases of various illnesses including enteric fever, scarlet fever, and diphtheria. The latter two are obviously childhood killers; they are rarely the cause of death in the first year of life (infancy) and relatively few people catch or die of these diseases after the age of 10 (see Pearson's graph reproduced in Figure 2.10).

Pearson reasoned that the laws of frequency, deduced from coin tossing and dice throwing, were the laws of all large numbers, including the age distribution of the frequency of death. The five law curves he saw in operation for age-determined mortality were frequency distributions that could be de-
scribed with equations (noted on Figure 2.7) from which values for a mode, mean, standard deviation, coefficient of skewness, maximum mortality in mode year, and total mortality covered by entire distribution could be determined (see Table 2.7). The skewed distribution of old age gave a theoretical limit to life that would not exist if the distribution were a normal one. Although only the curves for youth and middle age were strictly bell curves, all five curves were chance distributions.

The most interesting curve – and marksmen of death – is that of infancy. For one thing, Pearson’s equation for infantile mortality predicts the deaths before birth of 605 fetuses for every 1,000 live births, with most of these occurring within the first three months of conception.23 Pearson had not intended to go into this antenatal region, but the only equation that would fit the postnatal data took him there. The second striking feature of Pearson’s analysis of infant mortality was his linking it to heredity. Pearson’s commitment to the eugenic cause is blatant in his choice of a human skull as the weapon to typify the human encounter on the bridge of life with the most deadly marksmen of all, the marksmen for fetuses and infants. Pearson lay the blame for the “unremitting destructiveness” of infantile and fetal mortality with “bad parentage”: “The marksmen Death strikes down the young life with the bones of its ancestry” (Pearson 1897, 36). This choice is inconsistent not only with the visual metaphors of the other marksmen, but also with Pearson’s literal analysis of causes of death at other ages. Pearson was unable to perceive ways for reducing infant mortality other than state control of who should be allowed to prosper and multiply.24

With regards to the issue of biological evolution and the “numerical measures of the processes described by Darwin,” Pearson saw his work on the age distribution of mortality as helping to “localise the time and manner of selection” (Pearson 1897, 41). Pearson’s main theme, however, was illustrating the scientific reconstruction of the notion of chance. As Pearson saw it, “Our conception of chance is one of law and order in large numbers; it is not that idea of chaotic incidence which vexed the medieval mind” (Pearson 1897, 15). The data and hypothetical curves of mortality (Figure 2.7) drawn by Karl Pearson and the print of the “Bridge of Life” (Figure 2.8) etched by Maria Sharpe Pearson are both images of Pearson’s vision of “law and order in large numbers.” They are the visions of an applied mathematician schooled in geometry and the leisurely arts of gambling and archery; the visions of a well-

23 Note that the comparison by division of 605 fetuses with 1,000 live births is a ratio. The postnatal deaths at each age compared is 1,000 live births are proportions.
24 In Chapter 7 there are more details on the link between the eugenic movement and the development of statistical theory, including Pearson’s admiration of Adolphe Quetelet’s “experiments here, the dramatic decrease in the infant mortality rate over the past century has not been due to a state-controlled change in the gene pool. In 1994 only 6 out of 1,000 infants died in fetuses compared with the 152 deaths out of 1,000 infants Pearson recorded for the 1870s. That decline is due to changes in the environment in which the unborn and the newly born are nurtured – changes that stem from popular awareness of nutrition and hygiene, new medicals, a higher standard of living, and the more equitable distribution of prenatal and postnatal health care. The policy prescriptions implied by Pearson’s naming of the cause as bad ancestry would have been much less effective and caused far more strife than the adopted public health policies that have emphasized nurture rather than nature.