Comment on Oxley's "Seat of Death and Terror"*

Tim Leunig and Hans-Joachim Voth

Introduction

At its best, economic history can be a model for social science research. Open research questions lead to new data being collected. Additional empirical results offer new insights. Oxley's recent article *'The seat of death and terror'* attempts to advance our knowledge in this way. Taking its cue from our original article and the discussion in this *Review* that it caused, she brings new data to the question of how smallpox influenced heights.[1] We begin by summarising Oxley's main conclusions, before explaining why her evidence does not support them.

Oxley makes three claims: that smallpox reduced Londoners' heights, that this was not true for juveniles even in London, and that it was not true outside London.[2] This leads Oxley to conclude that "smallpox did not stunt growth", but is instead a proxy for overcrowding: "in terms of the urban and disease environment, Grosvenor Square was a million miles from St. Giles".[3] The poor were more likely to live in overcrowded conditions and so catch smallpox, but it was overcrowding, and perhaps the consequent disease environment more generally, not smallpox, that made them shorter.

Both the data and analysis in this paper are flawed, and the interpretation of results is misleading. First, Oxley's data collection method led to many observations being capriciously excluded. Second, the data collected is poorly classified, and suffers from arbitrary sub-division. Third, her data contradict her conclusion that smallpox mattered less for juveniles. We show that, contrary to Oxley's assertions, smallpox reduced the height of juveniles significantly, demonstrating the causal nature of the link between stature and the disease. Fourth, Oxley offers no evidence to support her claim about the link between smallpox and overcrowding. It is contrary to everything we know about the London disease environment at this time. Crucially, we show that the effect of smallpox does not differ by location – other Englishmen suffered no less than Londoners, and there is no evidence that smallpox proxied for overcrowding. In short, Oxley's new data offers resounding confirmation for our hypothesis that smallpox reduced heights.

I: The data and its collection

Oxley's claims are based on two new data sets, transportation records to New South Wales, and Wandsworth jail records. Oxley concentrates on the NSW data, noting that her "model fit is considerably better for transportees than for prisoners".[4] For

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[1] In keeping with the requirement of the Australian Research Council to make all of the data available to any researcher on request, two years after the data collection was completed. We thank Oxley for complying with this requirement.

[2] Oxley, 'Seat of death and terror', pp. 644, 645, 650 respectively.

[3] ibid., pp. 652, 649.

[4] Ibid., p. 643.

brevity we also focus our comments on that data set. Our criticisms apply equally or in greater strength to the smaller and less reliable Wandsworth dataset.

Oxley acknowledges that there are grave problems with the NSW dataset. Unlike the Marine Society data that we used, which explicitly recorded a person's own statements about their medical history. The NSW dataset only state whether someone had visible pockmarks. As she herself admits, "some 20 to 35% of sufferers failed to exhibit pockmarks".[5] We can see the scale of the problem by looking at the number of sufferers recorded. Of the London-tried transportees, for example, we find that while 20% of 21 year olds had had smallpox, only 11% of 22 years are recorded as having suffered the disease – despite both surely having grown up in the same disease environment. The data itself is fragile, and that means that Oxley's results will unavoidably be biased against finding an effect from smallpox. Both regression co-efficients and t-statistics will be biased downwards.

The dataset is extensive, but Oxley excludes significant numbers of observations. Ship one, for example, contained data on 197 men, of which Oxley collected data on only 163. We understand why 3 were omitted – they were born overseas, but 4 were omitted for being Welsh, and 20 for being Scottish. Since Oxley is interested in smallpox as a proxy for overcrowding, we find it odd that she should choose to exclude entries for Glasgow, for example. Even more surprisingly, 7 were omitted despite being English (including 4 from London). Oxley omitted these 7 (of which 2 had suffered smallpox) because they died on the passage to Australia. This is capricious: their death at sea cannot have influenced the interaction of smallpox and height prior to their departing England, and, as such, these entries should not have been excluded. Omitting valid observations is poor statistical and historical practice, and will lower the t-statistics, making it less likely that a significant result will be found even where a significant link exists.

II: The effect of smallpox on juvenile Londoners.

Oxley collected data on 11,504 NSW transportees, but restricts herself to the 2,420 cases that were tried in London. This is the single largest problem with her data handling. Despite the problems in the data, in the method of data collection, and in the restriction to a sub-sample, all of which bias downwards the size of the estimated co-efficient and/or the t-statistic on smallpox, Oxley still finds that those who suffered from smallpox were shorter than those who had not.[6]

Oxley argues that if it was smallpox itself that reduced height, we would expect the effect to be greater if we look only at the heights of juveniles, whose heights have had less opportunity to "catch-up" the height lost to smallpox. We made much the same point in our original article.[7] In this case there is a second advantage from ignoring older men: pockmarks may fade over time, making Oxley's data more reliable for young people than for older ones. Oxley reran the regression on the 1,244 London

[5] Ibid., p. 645.

[6] As Oxley herself acknowledges, the results strictly shows that those who definitely had had smallpox were shorter than another group some of whom had had smallpox and some of whom had not. The co-efficient thus understates the size of the actual effect of smallpox, ibid., p. 645.

[7] Voth and Leunig, 'Did smallpox reduce height?', p. 553.

tried transportees aged 21 and below, and finds that smallpox was not a significant determinant of height.[8] Oxley is usually diligent about stating how many of her sample had had smallpox, but she does not quote that statistic on this occasion. Inspection of her dataset shows that it contains just 158 smallpox sufferers, spread over a ten-year age span. In the appendix, we demonstrate that – because of the number of observations thrown away by this procedure – there is a 57% chance of obtaining insignificant coefficients *even if the true effect of smallpox was to reduce heights by 0.5 inches*.

Oxley's result is not robust to small changes in data handling. Her choice of 21 as a cut off age is arbitrary. It is not the case that there is a single well-defined age up to which – but not beyond – catch-up growth is possible. Rather, if smallpox causes stunting we should find that the effect is largest at younger ages, decreasing with age as the opportunities for catch-up decrease. Instead, therefore, of regressing smallpox on height for those below a particular age, in a particular place, we regressed height on smallpox for people below various different ages, up to the outer limit at which it is plausible that people stopped growing. We used all of the data, not just that for London, to increase statistical robustness. If smallpox stunted growth (and sufferers had a chance to catch up), then we should find the strongest effects at young ages of fast growth – and smaller ones later in life. As Oxley herself argued: "A study confined to those still in their growing years should reveal greater stunting… *if* smallpox stunted growth."[9] Her data show precisely this (figure 1). The estimated smallpox effect falls monotonically from age 15 – when growth as a result of the adolescent growth spurt tends to be high – to age 21, and appears to stabilize at slightly higher levels.

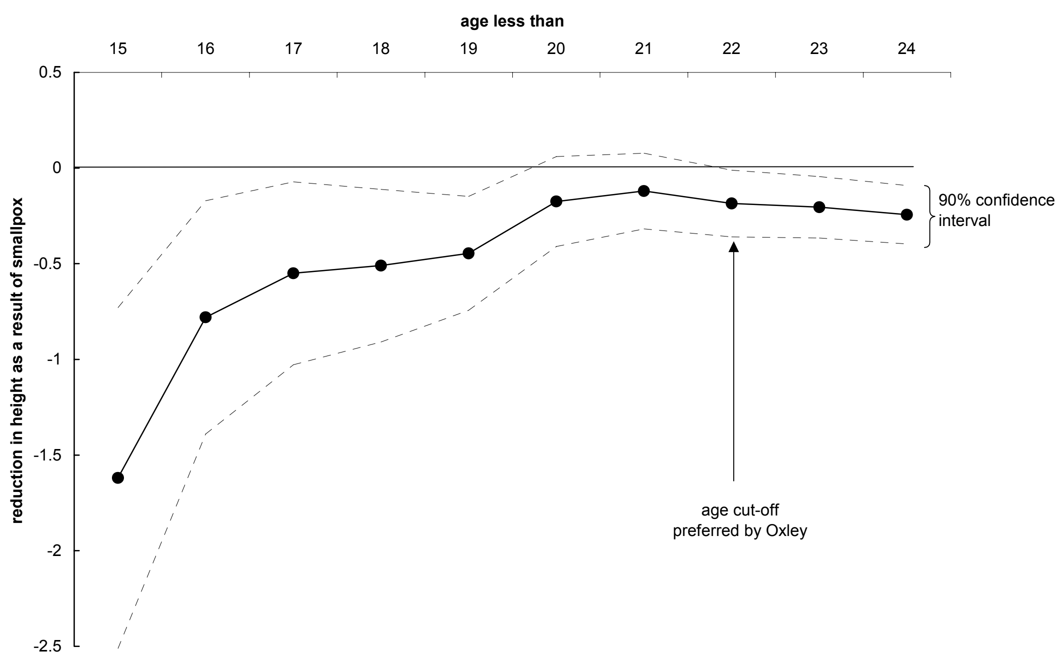

Figure 1: Impact of smallpox on average height, by age

[8] Oxley, 'Seat of death and terror', p. 645.
[9] Ibid., p. 645.

In eight of the ten cases, smallpox is a statistically significant and negative predictor of height, and in all ten cases the co-efficient is negative. It is most unlikely that this result would come about by chance: indeed there is less than a 0.1% chance of getting heads ten times if you toss a coin ten times. That two of the ten cases are not significant shows the limitations of this data: visible pockmarks are not the most reliable way to separate those who had smallpox from those who did not. In addition, exactly as we would predict, the co-efficient is largest at younger ages, declining to around a quarter of an inch by age 20. This is precisely what we expect if smallpox caused reductions in heights – it had the largest effect "on impact", and accelerated growth afterwards was only partially successful in eradicating it. That subsequent catch-up was only partial is to be expected: net nutritional status overall was low.

III: The effect outside London

In order to strengthen her claim that smallpox in London is merely a proxy for overcrowding, Oxley investigates the effect of smallpox the rest of the United Kingdom. She claims to find no effect from smallpox outside of London: "The association between pockmarks and stunting in London is unique."[10] Her data show the opposite.

Oxley's classification of NSW transportees into urban and rural counties is highly unreliable. She classifies transportees according to whether they came from rural or urban counties. She admits that this classification is often poor, noting that Lancashire, for example, included large rural areas, as well as Liverpool and Manchester, while rural counties often included large conurbations, and London includes all of Kent, Essex and Surrey.[11] If the data only gave the transportees' county, such a classification might be necessary, but this is not the case. The original records, which we have inspected, simply ask the 'native place'. In some cases a county is given, but in general the town itself is recorded. Over 60% of the 155 English observations that Oxley takes from the first ship, for example, give the name of the town. Oxley takes the name of the town, finds its county, and then decides whether that county is urban or not. It would have been more reliable to count those who stated that they lived in towns as living in towns, and those who gave only a county as their designation as living in rural areas.

The original data also give the transportees' work. Many descriptions are obviously rural: carter, farm, groom, milk, plough, reap, shears, shepherd, sow and stable, for example. Oxley did not collect this data, even though it would have allowed her far greater precision in deciding which transportees came from rural areas. That omission is not helpful. As a result, Oxley's division of workers into different geographical entities is far more arbitrary than was possible with the data available. This is true even in the case of London, where, for example, Oxley classifies as living in London two 21 year olds who state explicitly that they lived in Tenterden, a small Kentish village 60 miles – a day's journey – from London. This is, sadly, by no means an isolated example of such errors.

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[10] Ibid., p. 651.
[11] Ibid., p. 648

Not withstanding these problems, Oxley finds a negative co-efficient on smallpox in all four of her categories, with London the only statistically significant result. We make two points, one suggesting that Oxley's regression is poorly set up, the second that the results are misinterpreted. First, Oxley's non-London sample often have few young smallpox sufferers. As we have seen, the effect of smallpox is more pronounced among the young, and so we need a decent number of younger transportees if we are going to be able to test whether smallpox reduced heights.

Table 1: Effect of smallpox, by subsample, NSW-data

	London	**English rural**	**English urban**	**Irish**
Oxley's smallpox coefficient	-0.440	-0.061	-0.193	-0.143
t-statistic	2.94	0.41	1.31	1.34
proportion of all smallpoxsufferers by age in geographical subsample				
Under 20	32%	19%	27%	21%
N under 20	93	56	88	132
Under 18	15%	6%	10%	9%
N under 18	43	18	33	58

As table 1 shows, the larger the number of young smallpox sufferers, the stronger the stunting effect of smallpox. Where there is only a small number of young smallpox sufferers, as with the English rural population, the estimated coefficient is small, and the t-statistic low. Where the proportion is high, as in the case of London, the recorded effect is strong – precisely as we would expect if smallpox stunted growth at the time of the disease, with some catch-up possible later on.

Remember too that even in Oxley's regression all of the coefficients were negative. Oxley notes this, remarking that 'none the less, it is intriguing that in each case pockmarks were associated with a negative effect'.[12] Basic probability theory shows that it is more than intriguing: the chance of throwing 4 heads out of four is just 6%. To a statistician, consistent coefficients and insignificant t-statistics show that the data have been excessively and inappropriately divided. Oxley's technique is equivalent to concluding that people do not grow taller over time, because when we compare heights and ages, for example, on individual ships, the co-efficient on age is rarely significant. Should we conclude that people do not grow as they get older, because that appears to be true for most ships? Of course not: the consistently positive but not significant co-efficient on age shows that subdividing the data by boat is inappropriate.

The standard technique for using all the information in the various subsets is "meta-analysis", used extensively in medical statistics, where data is often gathered from small, separate clinical trials.[13] We want to know the likelihood that the negative

[12] Ibid., p. 651.
[13] Egger and Smith, 'Meta-Analysis. Potentials and Promise'.

coefficients in all four UK areas have come about by chance. We use the Sharp-Sterne implementation of the meta-routine.[14] The results are given in table 2.

Table 2: Meta analysis results

	London	**English Rural**	**English Urban**	**Irish**	**Meta analysis**
Oxley's smallpox					
coefficient	-0.440	-0.061	-0.193	-0.143	-0.196
t-statistic	2.94	0.41	1.31	1.34	(2.93)

Note: Meta analysis includes fixed effects, z-value in parentheses

The meta analysis gives an estimated negative coefficient of minus 0.196 inches, statistically significant at the 1% level. Considering all the evidence from the different regions of England jointly, the conclusion has to be that smallpox made you significantly shorter. Nor is there any evidence that the effect varied by location -- the Q-test for heterogeneity yields a statistic of 3.7, which is insignificant (p-value 0.29). There is, therefore, no reason to believe that the variation across subgroups arose by anything other than chance: smallpox reduced heights, and it was just as effective at reducing heights outside of London as inside the capital.[15]

III: Overcrowding

Rather than accepting that smallpox reduced height because it was a terrible disease Oxley prefers to believe that smallpox was a proxy for overcrowding, which caused stunting either because it was associated with lower nutritional intake, or because it implied more extensive chronic conditions. As we showed above, the data from the different regions of England directly contradict Oxley's key finding on which her case rests – that only Londoners showed an association between smallpox and height. There are also three additional reasons to reject her hypothesis.

It is incompatible with Oxley's data, in two senses. First, if smallpox is a proxy for overcrowding, we should expect smallpox to be more common amongst overcrowded Londoners. This is not what her data show – 13.7% of Londoners had smallpox, compared to 14.8% for other English urban areas, 15.6% for Ireland, and 9.4% for English rural areas. Oxley's logic would suggest that Ireland had more overcrowding than London.

Second, Oxley claims that those who had not suffered from smallpox lived in better areas: "Wealth might not assist a mucous membrane in resisting an infective particle once it has been inhaled, but it could reduce the chance of encountering the *variola* virus in the first place by purchasing private space. In terms of the urban and disease environment, Grosvenor Square was a million miles from St Giles.".[16] Over 85% of the London sample had not suffered from smallpox. Oxley wants the reader to believe that 85% of criminals convicted in London to be transported to Australia lived in Grosvenor Square and such like. That is contrary to everything we know about the

[14] Hedges and Olkin, *Statistical methods for meta-analysis*.
[15] This result is robust. When, for example, we exclude London altogether and restrict ourselves to non-London England and Ireland we still find that smallpox statistically height, and that the size of the effect does not vary by place. The same is true if we restrict the analysis to those aged under 22.
[16] Oxley, 'Seat of death and terror', p. 649.

social background of convicts in this era, the overwhelming majority of whom would have come from poor backgrounds, and would have suffered from overcrowding. It is also contrary to what we know about the backgrounds of those who had suffered smallpox: as we showed in our original article, smallpox sufferers had a similar chance of coming from a female-headed household as those who did had not suffered the disease.[17]

Third, Oxley wants us to believe that Grosvenor Square and St Giles are a million miles apart in terms of disease. The evidence shows that they are side by side, both geographically and in terms of the spread of disease: in the smallpox epidemic of 1772, for example, St Martin's district – which includes such affluent parishes as St James Piccadilly, and St George Hanover Square had slightly higher crisis mortality rates than did St Giles, Southwark, or City districts, but slightly lower levels than Holborn or Cripplegate.[18] Smallpox was a disease that could spread easily and rapidly within London, independent of social status.

IV Conclusion

Oxley brings a new and important data source to the question of smallpox's effect on stature. The data are not ideal, because a visual inspection for pockmarks is not an accurate method of estimating whether someone had had the disease, especially at older ages. A quarter of smallpox sufferers will be misclassified, and as such, all results will be biased downwards.

Nevertheless, Oxley's data shows more convincingly than was previously possible that smallpox reduced heights. The number of observations at younger ages allows us to understand the effects of smallpox in a way that had not previous been possible. We show that the smallpox effect was very large "on impact" – perhaps 1.5 inches, falling to between a quarter and 0.4 of an inch by adulthood.

Oxley is right that the detrimental effect of smallpox was clearly visible in London, but incorrect that it was not present elsewhere: that result came from poor sample composition and haphazard data handling. Smallpox reduced heights inside and outside London, and there is no evidence that the magnitude of this effect differed by location. Oxley's claims that smallpox was a proxy for overcrowding cannot be entertained: it is not credible to claim that overcrowding was less likely within London than outside, nor that 85% of prisoners would have come from salubrious areas characterized by generous amounts of individual private space.

Smallpox did reduce height. The estimated effect is greater when the quality of the data and data collection are better, greater when the sample size is larger, and greater when the number of people in the data set are young. The last is important. The effect of smallpox was most pronounced in the young, with older people partially making up the initial height shortfall. Oxley's new data adds additional certainty our initial conclusion that suffering one of the worst diseases in the history of mankind also affected stature.

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[17] Voth and Leunig, 'Did smallpox reduce height?', p. 550.
[18] Landers, *Death and the metropolis,* p. 307.

Appendix:

To demonstrate the problems caused by Oxley's discarding almost 90% of her observations, we conduct the following experiment. Assume that smallpox actually reduced heights by 0.5 inches, to 64.5 inches on average. Assume also that sufferers and non-sufferers are distributed with the standard deviations from Oxley's full sample. We use a random number generator to obtain two distributions to match Oxley's full sample – 9,965 and 1,539 respectively.[19] We now draw a random subsample, equal to Oxley's preferred sub-sample of 1,086 people without smallpox, and 158 with the disease. How often should we be able to demonstrate that a statistically significant difference exists between these two groups?

We did this experiment 1000 times. On average, we found a difference in height of 0.501 inches,[20] but in 57.4% of cases the result was not significant at the 5% level.

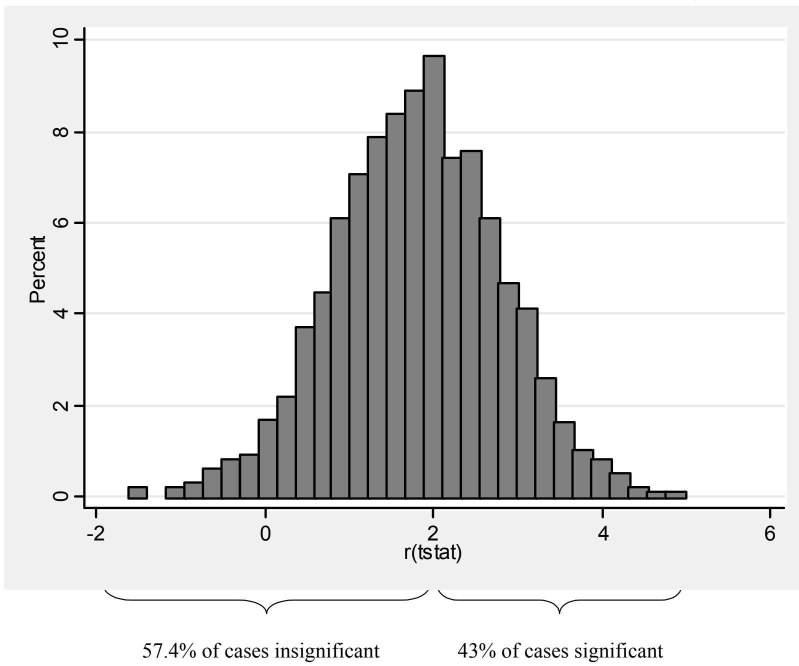

Figure 2: Distribution of t-test statistics from Monte Carlo simulations with 1,000 replications for true differences of 0.5 inches

Given how much data is deliberately left aside by Oxley because she restricts her the sample to (i) only those born in England (ii) tried in London (iii) under the age of 22, we are at least as likely to obtain an insignificant result as a significant one *even if the true difference between the heights of smallpox sufferers and those unaffected is 0.5 inches.*

[19] The Stata do-file that performs the Monte Carlo simulation is available at http://www.econ.upf.edu/~voth/oxleymc.html

[20] According to the law of large numbers, as the number of replications approaches infinity, the average difference in height of the two distributions should approach 0.5.

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