What *really* happened in the English Industrial Revolution?

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Abstract

England, during the period leading up to and spanning the first Industrial Revolution, learned how to consume a virtually unconstrained quantity of fossil carbon energy. This led directly to modern economic growth for the first time in recorded history. Studying the event empirically, I use recent long-period series estimates of the rate of English energy consumption, Gross Domestic Product, and population to test the hypothesis that this was primarily an *energy* revolution with important but very limited institutional/cultural support.

The outcome should provide insights into economic development for development economists, highlighting the importance of energy transitions for growth of economic systems. Additionally, the analytic framework I develop can be applied across time and geography, adding insights to ongoing development puzzles.

Table: Taxonomy of EIR explanations

Label	Examples
English exceptionalists	Landes (1969), McCloskey (2010), Mokyr (1992,2010)
Partial culturalists	Cipolla (1966), Pomeranz (2001), Allen (2009)
Primarily energetic	Cottrell (1955), Wrigley (1988,2010), Malanima (2010)
Thermodynamicists	Georgescu-Roegen (1975), Ayres (2003), Garrett (2009)

Table: Data Sources

Data series	Year range	Geography	Source
Energy consumption	1300 – 1873	England/Wales	Roger Fouquet (2008)
Gross domestic product	1300 – 1700	England	Graeme Snooks (1994)
	1741 – 1873	England/Wales	Lawrence Officer (2009)
Population	1300 – 1540	England	Graeme Snooks (1994)
	1541 – 1800	England	B. R. Mitchell (1988)
	1801 – 1873	England/Wales	B. R. Mitchell (1988)

Table: growth rates by century

Year	1300	1400	1500	1600	1700	1801	1873	Total
GDP Million 2005 GBP	3114.7541	815.1288	994.4571	6031.953	8361.5911	18110	102811	
Century-over-century rate of growth		-0.738	0.220	5.066	0.386	1.166	4.677	32.008
Compounded annual rate of growth		-0.013	0.002	0.018	0.003	0.008	0.024	0.006
Energy consumption	1.7	1	1.3	2.2	3.6	11.6	66.1	
Century-over-century rate of growth		-0.412	0.300	0.692	0.636	2.222	4.698	37.882
Compounded annual rate of growth		-0.005	0.0026	0.005	0.005	0.012	0.024	0.006
Per-capita GDP 2005 GBP	542	329	421	1,484	1,663	1,999	4,392	
Century-over-century rate of growth		-0.393	0.282	2.521	0.121	0.202	1.198	7.108
Compounded annual rate of growth		-0.005	0.002	0.013	0.001	0.002	0.011	0.004

Table: Energy and GDP fit tests

Test	Statistic	p-value
Pearson's correlation	0.998	
Paired t-test	5.592	4.991e-07
Chi-square	2864	0.0004998

Table: granger tests of energy/gdp

Era	Energy ~ GDP Pr(>F)	GDP ~ Energy Pr(>F)	AS/AD regime
1300 – 1500	0.0106	0.0003	EMP, Black Death, wages/family income increasin
1500 – 1600	0.1939	0.6126	Positive demand shock
1600 – 1750	0.3529	0.5185	Energy supply constraint
1750 – 1873	0.0024	0.1100	Positive supply shock, “virtuous” macro feedback cycl
1300 – 1873	0.0002	0.0361	Total study period

Figure: Author/time-span series of energy consumption, GDP, and population

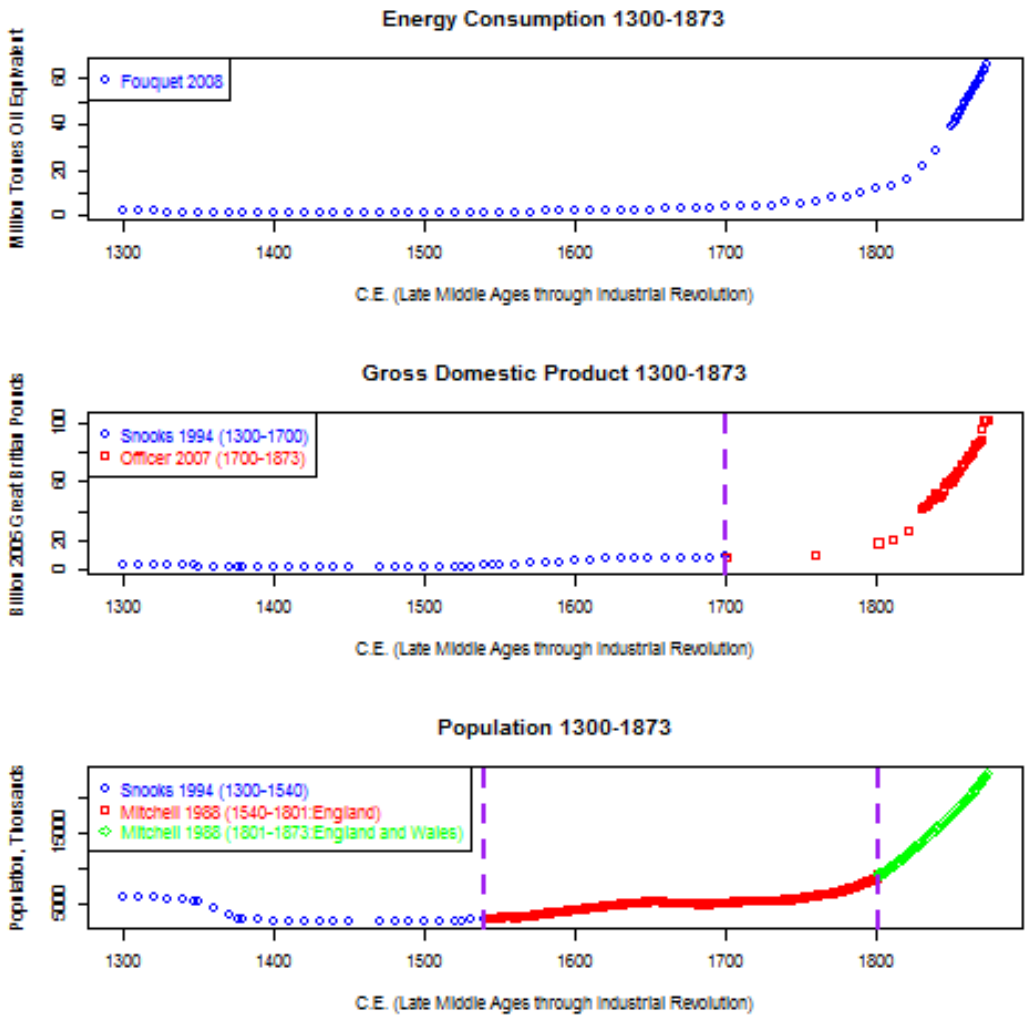
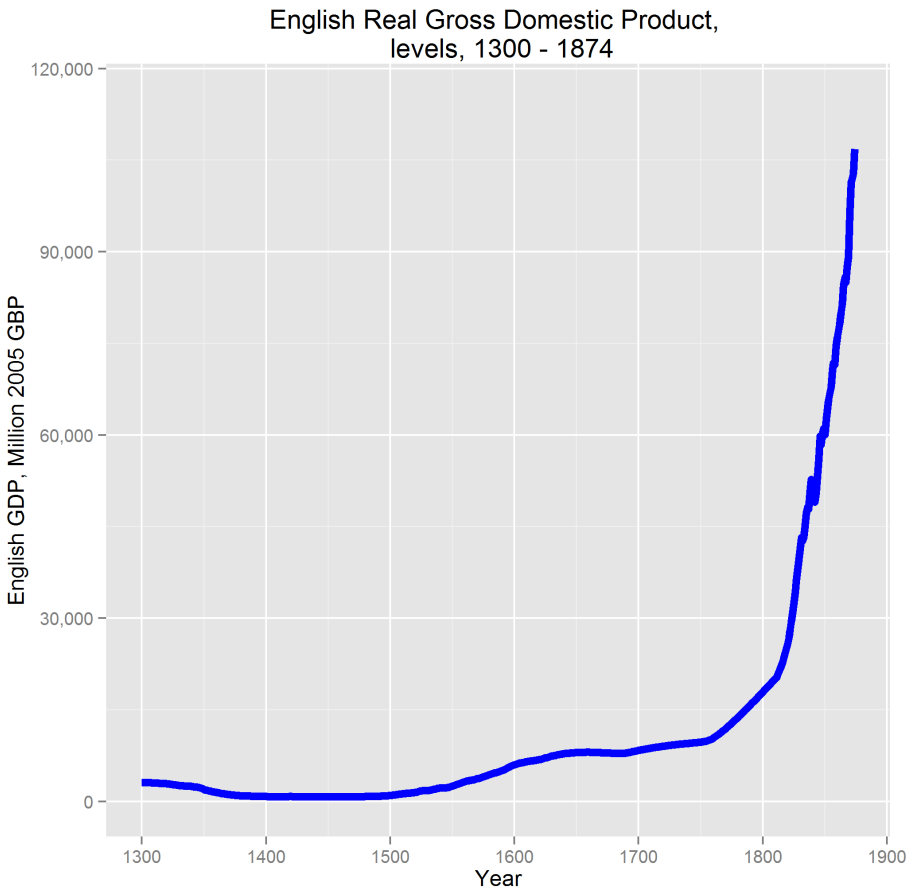


Figure: English real gross domestic product, levels and per–capita



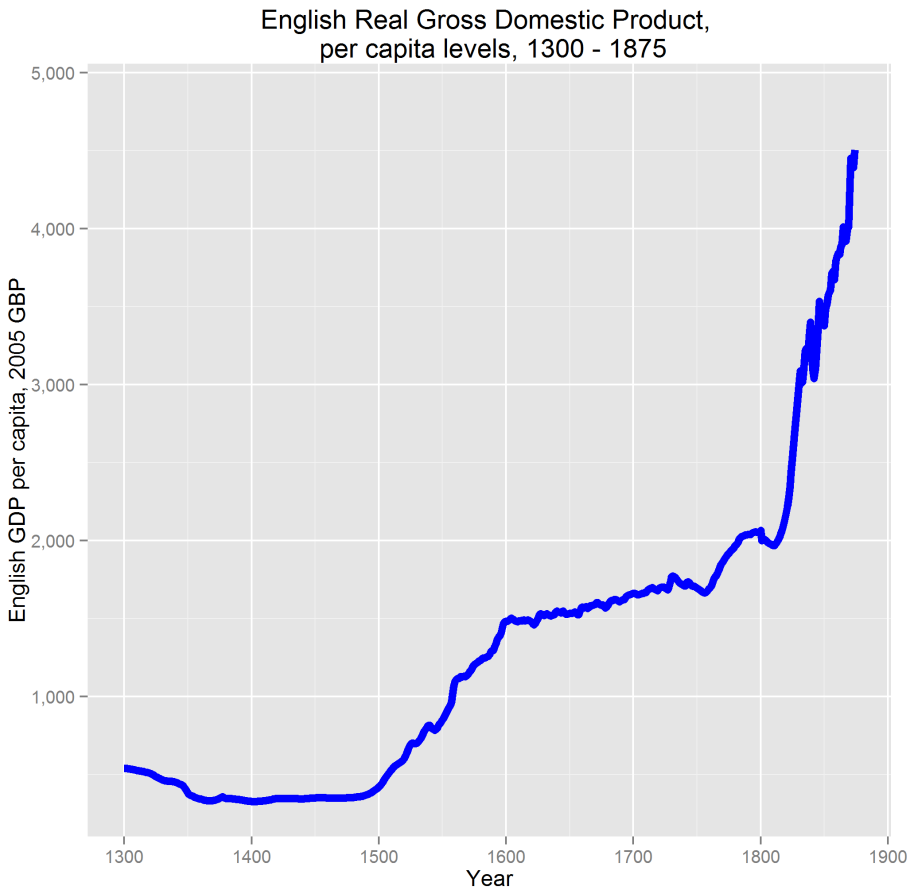
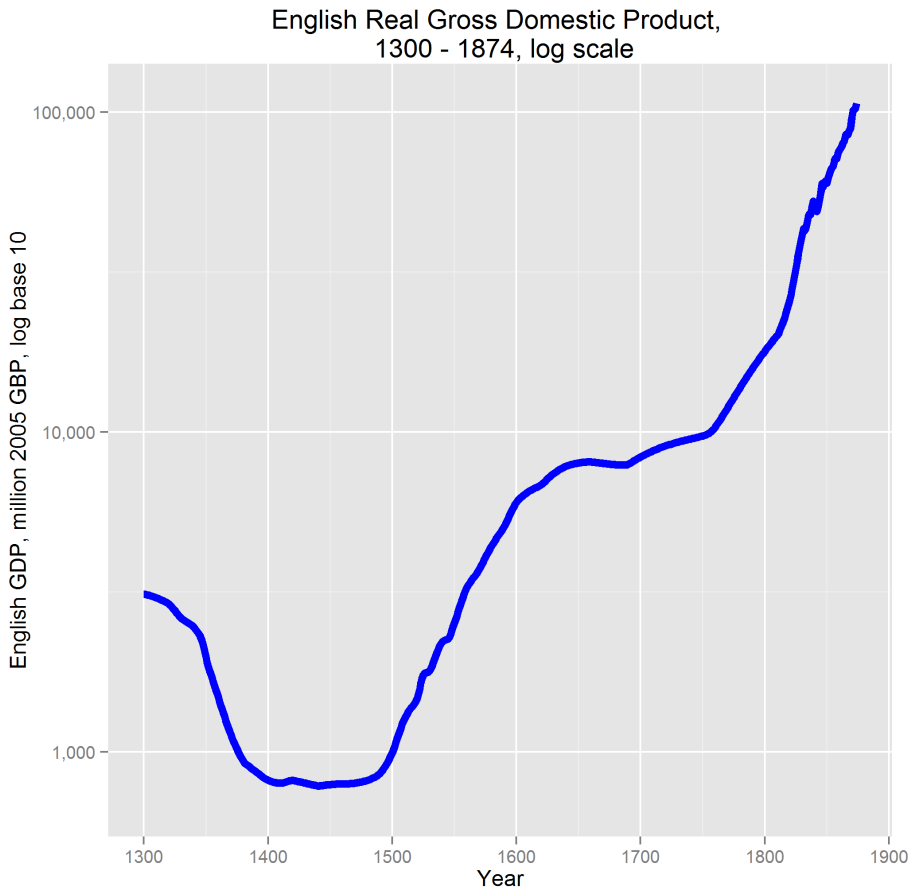


Figure: English real gross domestic product, log levels and log per–capita



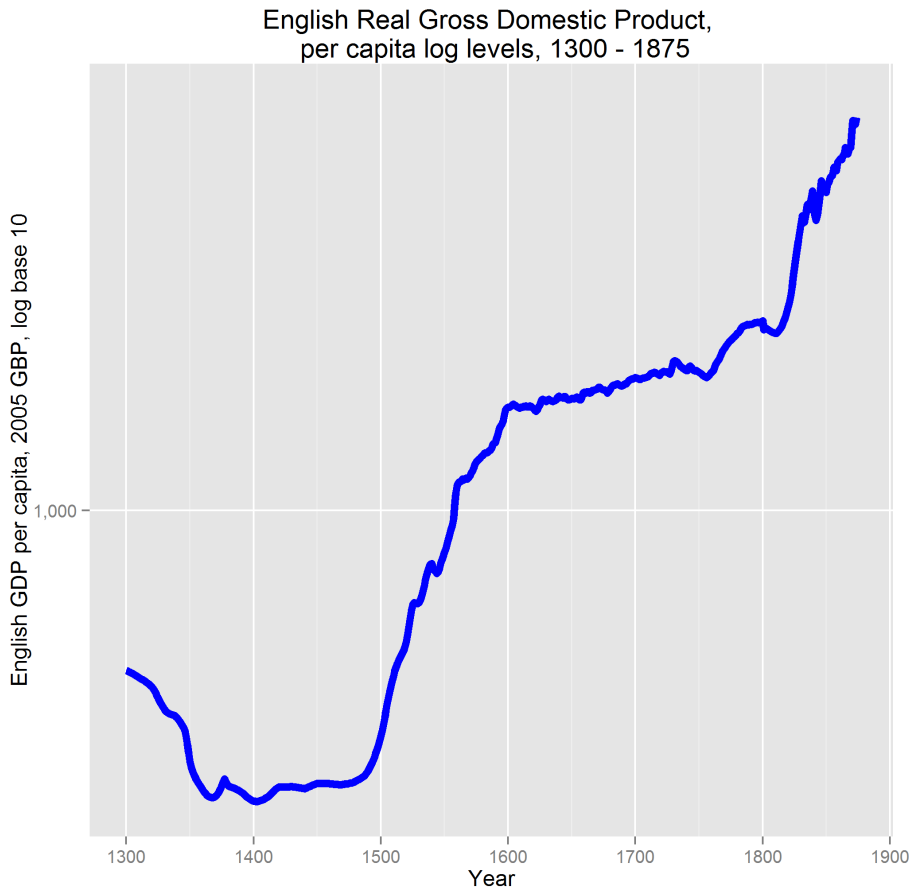


Figure: Log of population, with structural breaks

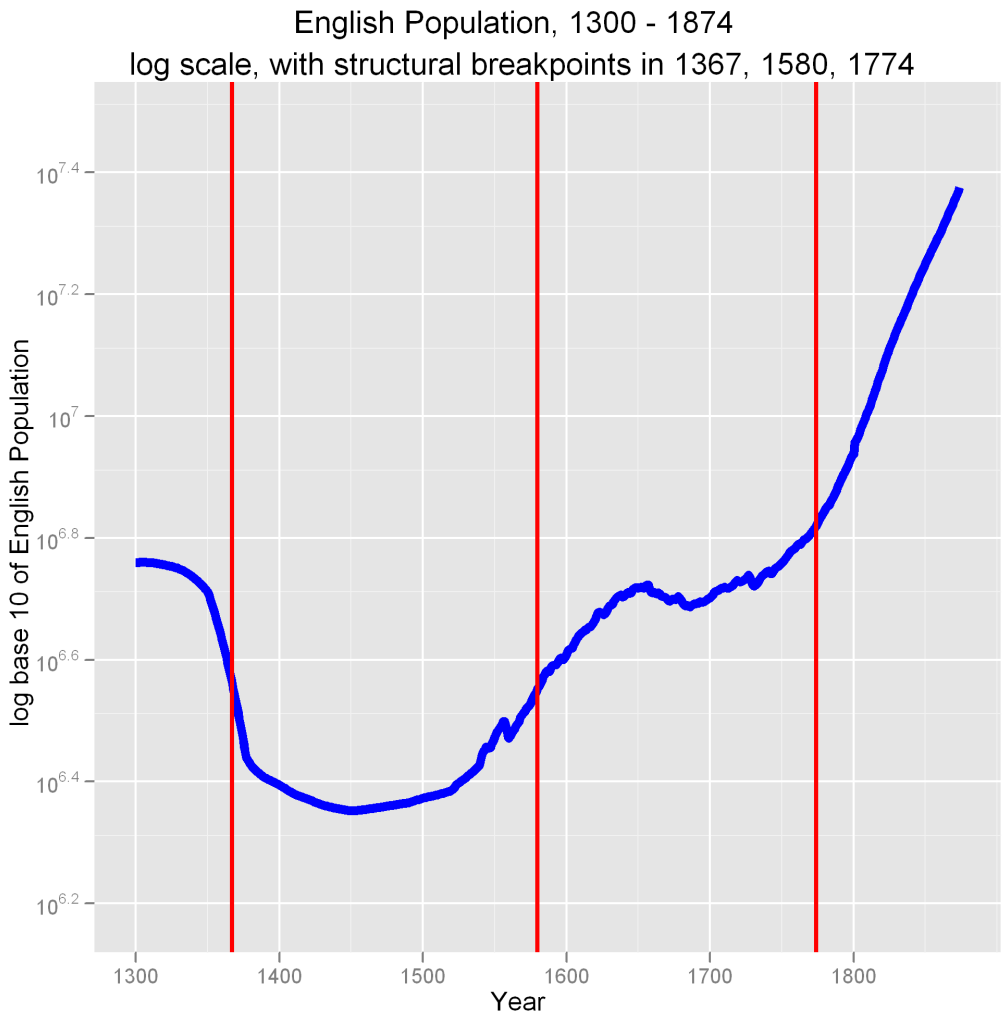


Figure: Log of energy consumption, with structural breaks

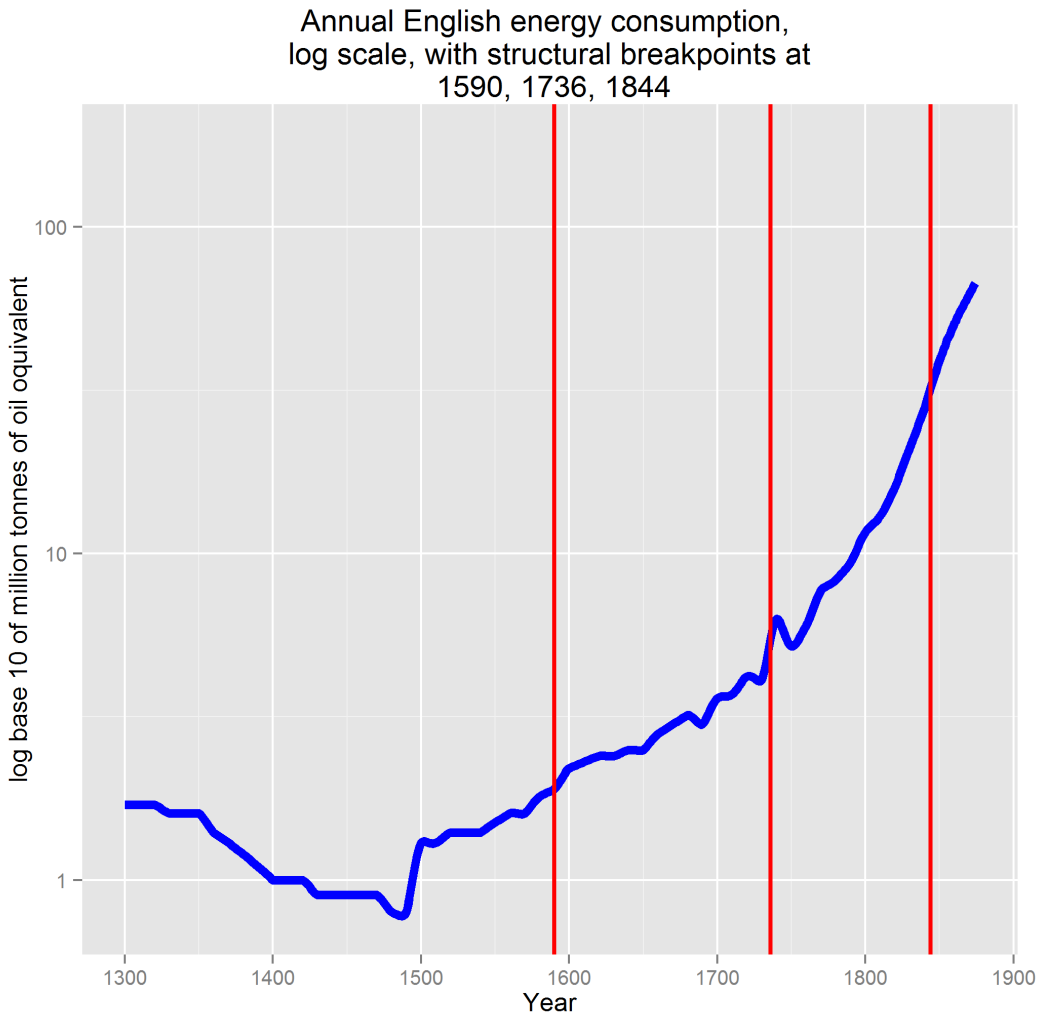


Figure: Energy consumption vs. standarized GDP

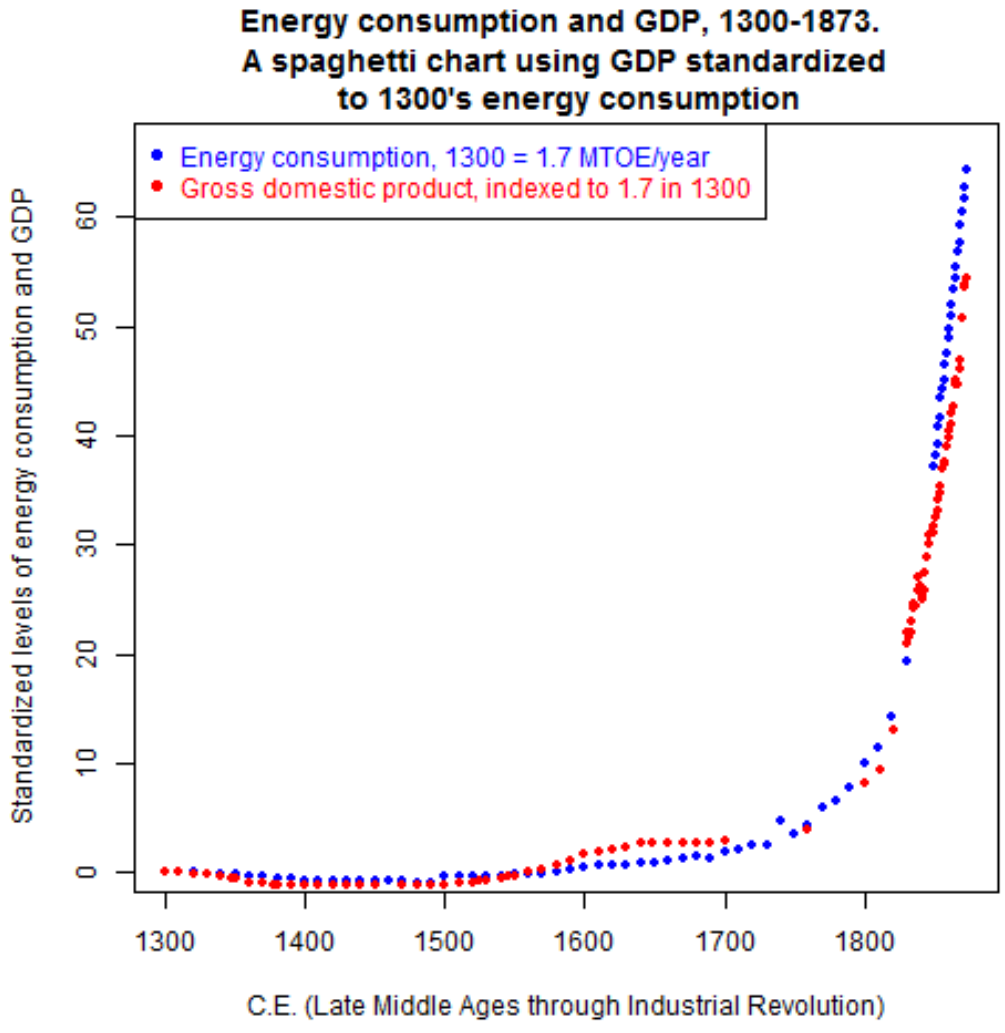


Figure: Energy consumption vs. standardized GDP, differences

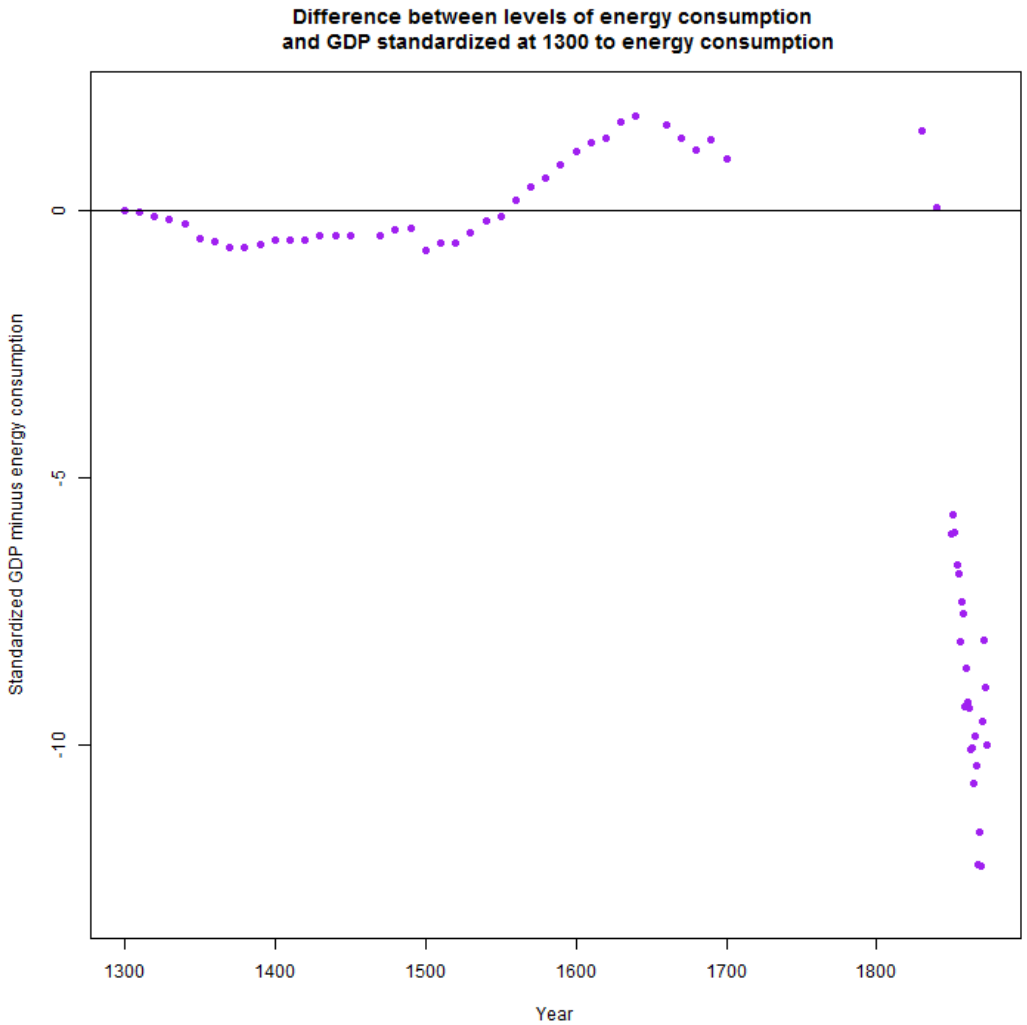


Figure: Scatterplot of energy consumption vs. GDP

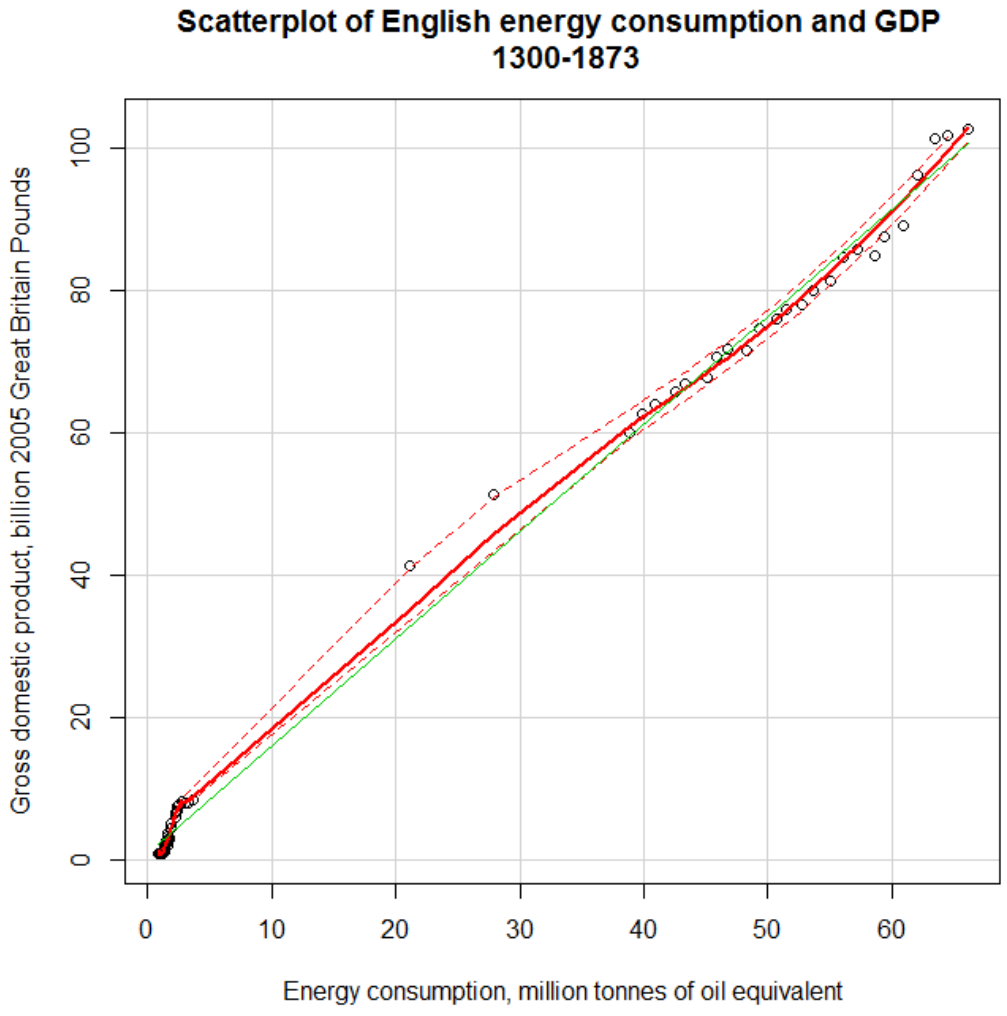
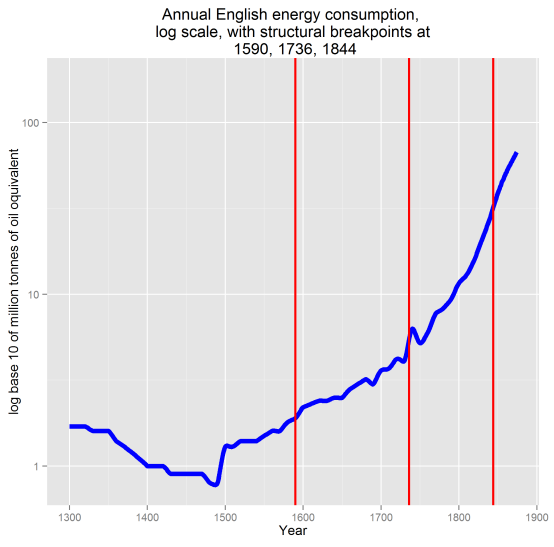
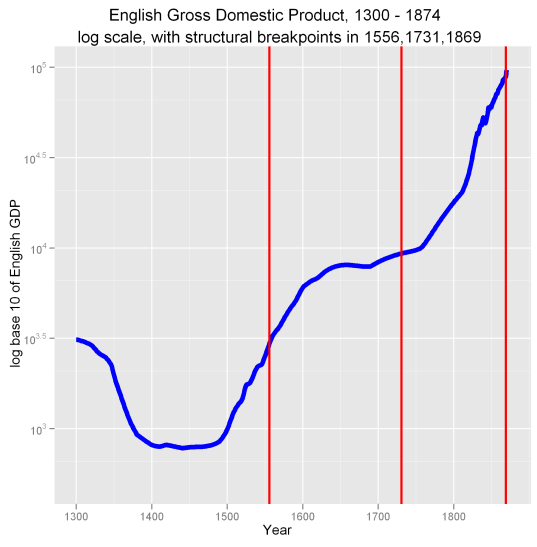


Figure: Structural break comparison





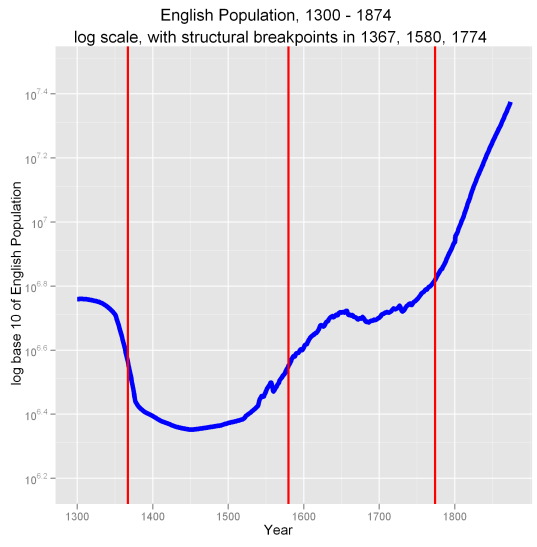


Figure: Coal and wood energy sources
Source: Pearson & Fouquet

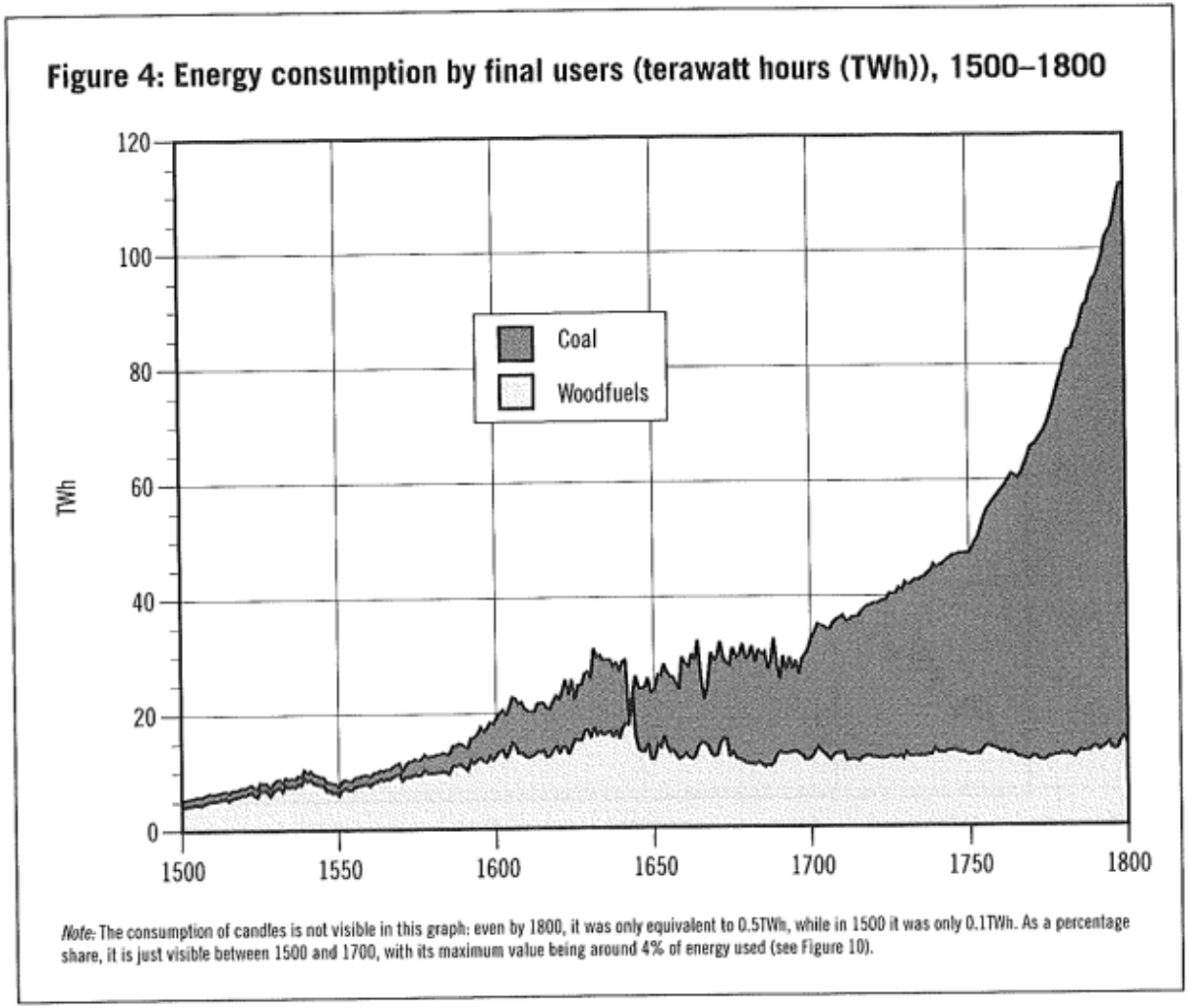
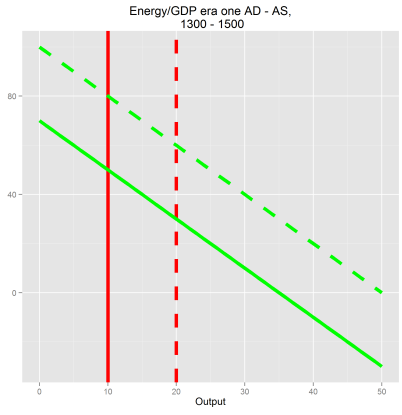
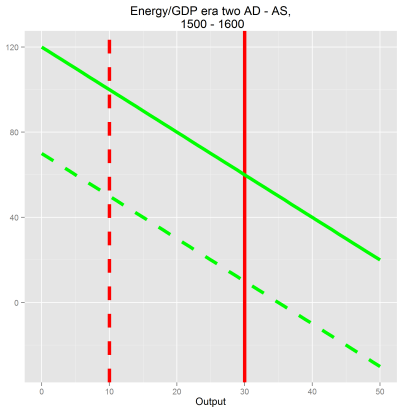
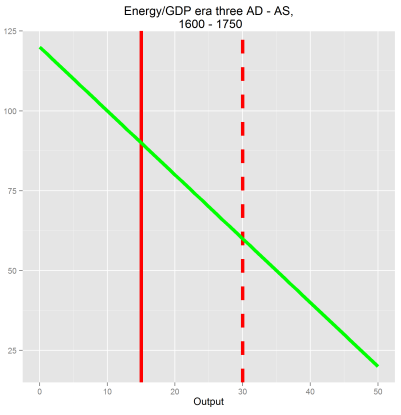


Figure: Aggregate Supply - Aggregate Demand
Four energy/GDP regimes







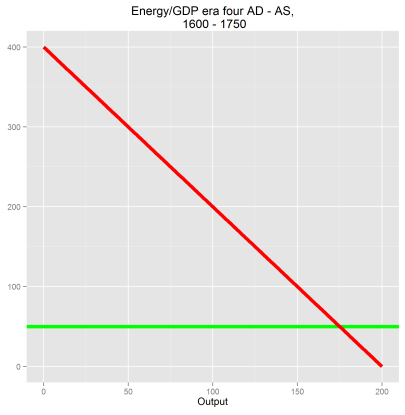


Figure: Desagulier manuscript

rection P *p*, and a Quantity of Water [illegible] be lifted up, and run out at P. This may be done 15 or 16 times in a Minute, becauſe each Man would pull down but 30 Pounds at a time, after the manner that People ring Bells. But as no Time is to be loſt, leſt the Mine be overflow'd by the Springs below, there muſt be 100 more Men to relieve thoſe when they are weary. Now as it muſt be a rich Mine indeed whoſe Profit can afford to keep 200 Men at this Work; that

Lect. XII. Plate 36. that Thought muſt be laid aſide. We'll conſider therefore what can be done by Horſes. As an Horſe is equal to five Men, we muſt work 20 Horſes at a time to raiſe the Water requir'd; and as Horſes muſt be reliev'd even more than Men, about 50 Horſes muſt be kept to carry on this Work conſtantly, and bring down the End of the Beam *b*, 16 times in a Minute, and make the number of Strokes requir'd in the Pump, the Weight of whoſe Rod after every Stroke will bring down the End *b* 2, by drawing along the Tangent *i* H. It is plain to any body, that tho' the Horſes may be had cheaper than Men, yet that will be a very expenſive way. For the next Contrivance, we'll ſuppoſe a Philoſopher to come, and find a means to bring down the End of the Beam, without Men or Horſes, in this manner. To the Chain H L he fixes a

Figure: Real wage to energy ratios
Source: Robert Allen (2009)

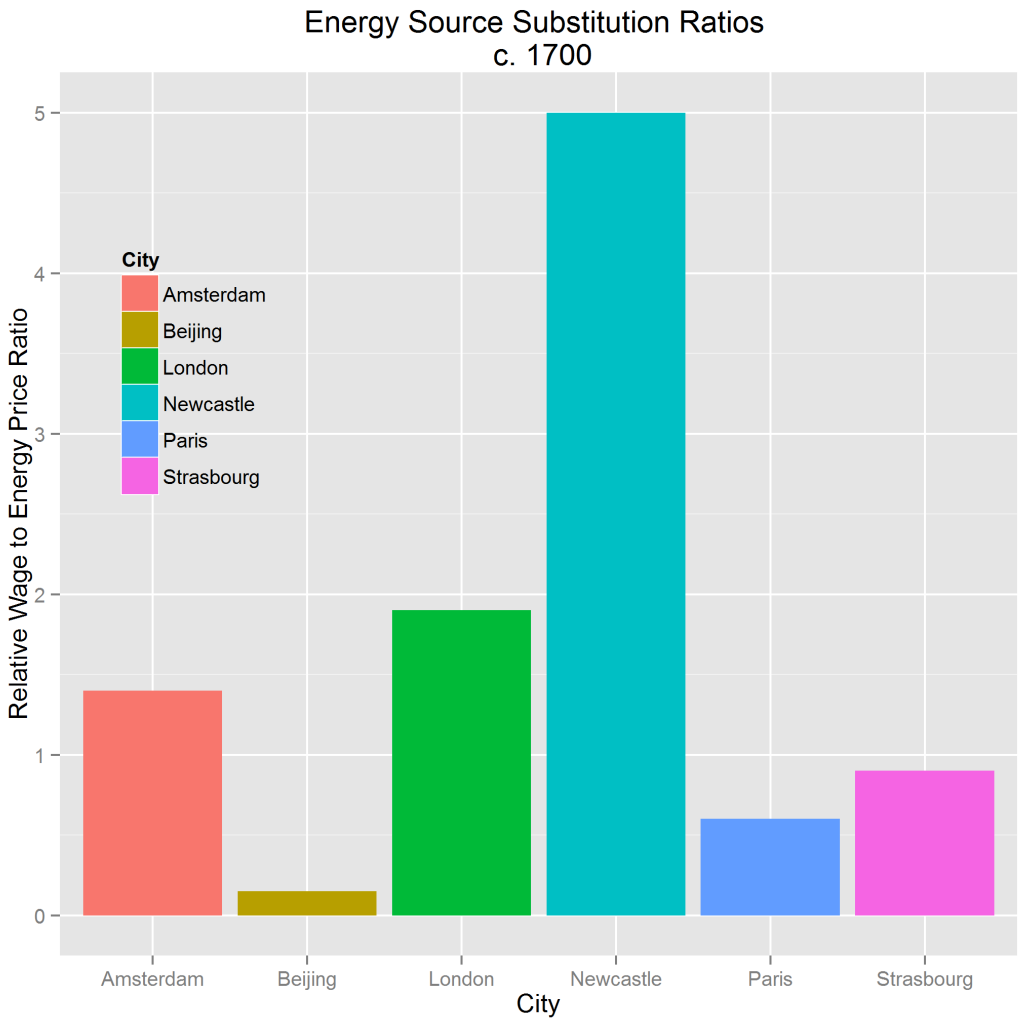


Figure: Standardized English energy intensity of GDP

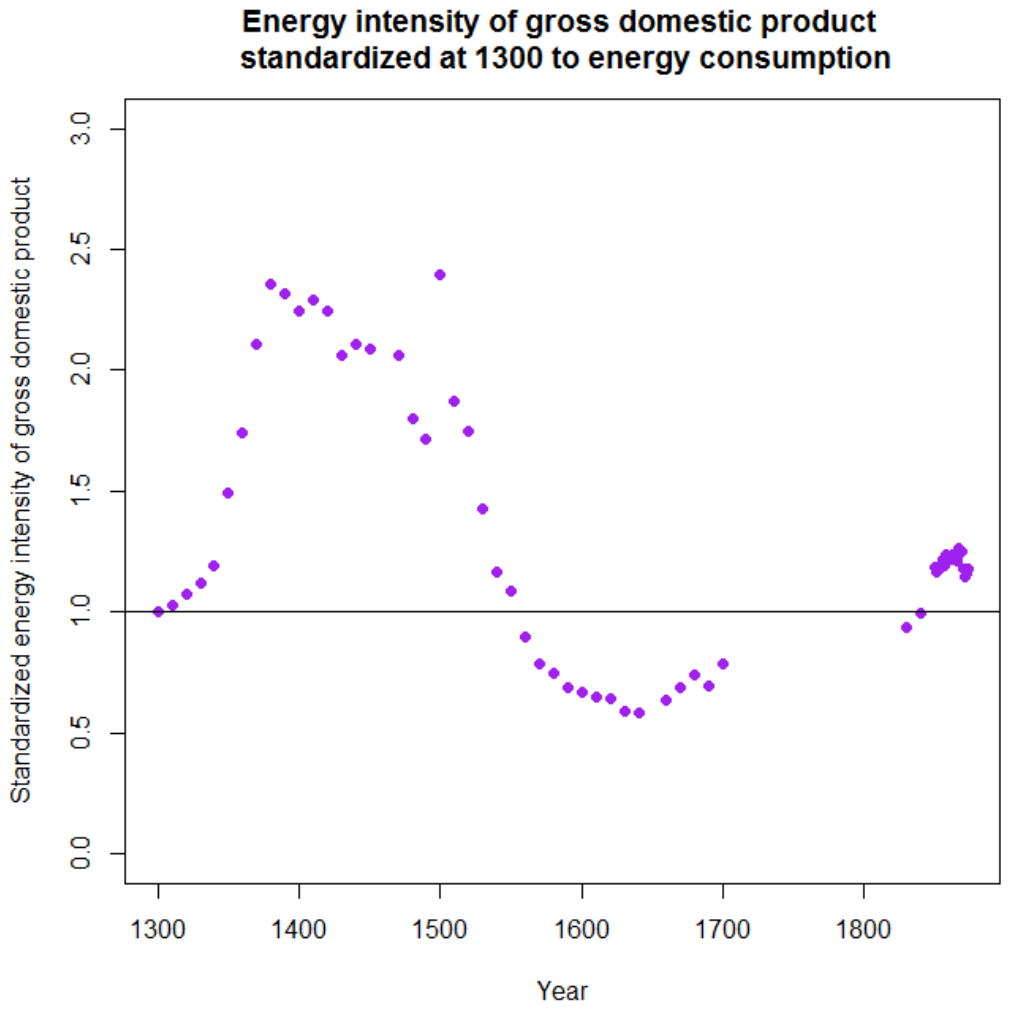
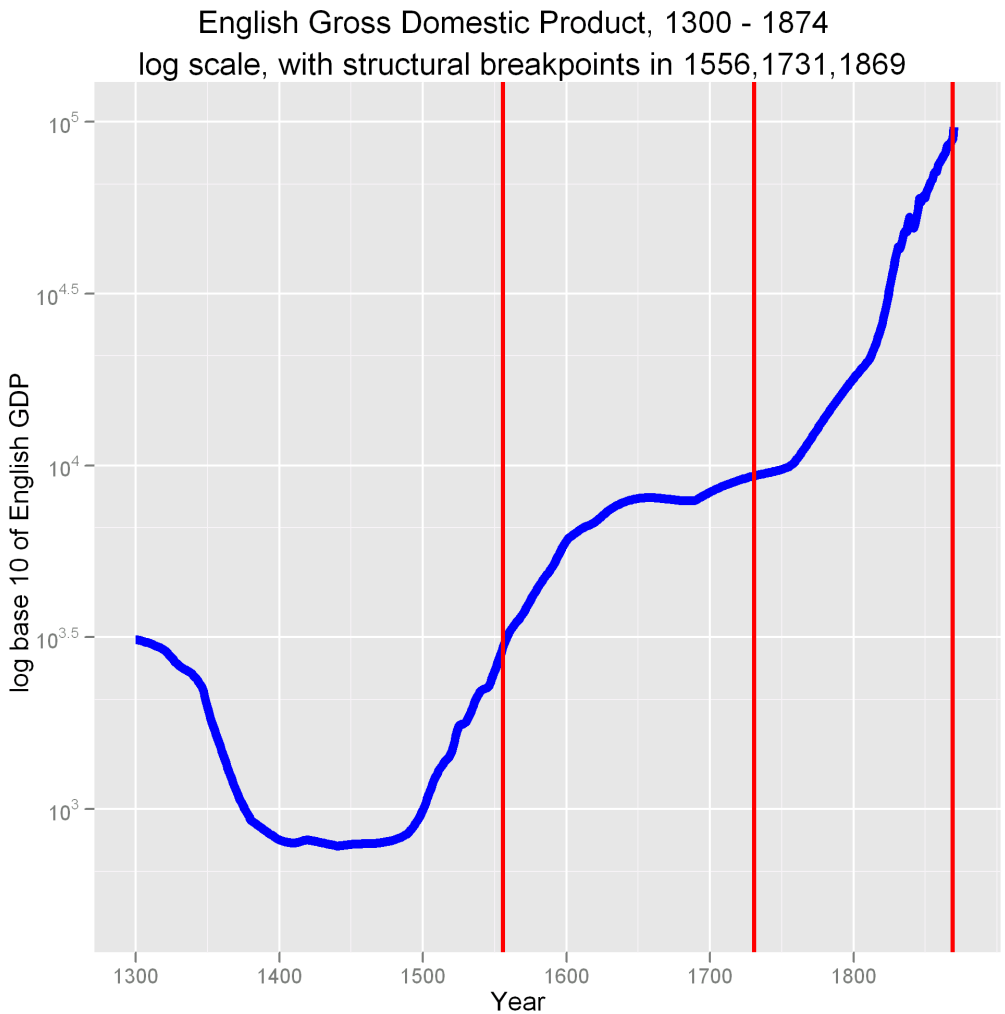


Figure: Log of GDP, with structural breaks



$$\frac{\text{Marginal Revenue Product}_{\text{organic energy joule}}}{\text{Price}_{\text{organic energy joule}}} = \frac{\text{Marginal Revenue Product}_{\text{fossil energy joule}}}{\text{Price}_{\text{fossil energy joule}}} \tag{1}$$