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Adam Smith, Watch Prices, and the Industrial Revolution.

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Abstract

Although largely absent from modern accounts of the Industrial Revolution, watches were the first mass produced consumer durable, and were Adam Smith's pre-eminent example of technological progress. In fact, Smith makes the notable claim that watch prices may have fallen by up to 95 per cent over the preceding century; a claim that this paper attempts to evaluate. We look at changes in the reported value of over 3,200 stolen watches from criminal trials in the Old Bailey in London from 1685 to 1810. Before allowing for quality improvements, we find that the real price of watches in nearly all categories falls steadily by 1.3 per cent per year, equivalent to a fall of 75 per cent over a century, showing that sustained innovation in the production of a highly complex artefact had already appeared in one important sector of the British economy by the early eighteenth century.

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The diminution of price has ... been most remarkable in those manufactures of which the materials are the coarse metals. A better movement of a watch, that about the middle of the last century could have been bought for twenty pounds, may now perhaps be had for twenty shillings.[a]

[a] *Wealth of Nations*, Bk 1 Ch 11 Pt 3 "Effect of the Progress of Improvements on the Real Price of Manufactures."

Adam Smith

1 Introduction.

Most recent studies of the Industrial Revolution focus on the sustained innovations in the three sectors of textile spinning, iron making, and steam power that began in Britain in the latter half of the eighteenth century. However, to one usually well informed contemporary observer, things appeared quite different. Discussing technological progress in *The Wealth of Nations* Adam Smith (1976, 270) ignores most of the famous inventions in these sectors, and instead chooses as his paradigm of technical progress one good that is entirely absent from most current histories of the Industrial Revolution: watches. In fact, Smith makes the notable claim that the price of watches may have fallen by up to 95 per cent over the preceding century, a claim that we attempt to evaluate here.

To test whether watch prices had been falling steadily and steeply since the late seventeenth century we use the records of over 3,200 criminal trials at the Old Bailey court in London from 1685 to 1810.[1] Owners of stolen goods gave the value of the items they had lost, and, because watches were frequently stolen, we can reliably track how their value changed through time.

Contemporaries divided watches into two categories, utilitarian silver or metal watches; and more expensive gold ones. Adjusting for inflation, the price of each type of watch falls steadily by 1.3 per cent per year, equivalent to a fall of 75 per cent over a century. If we assume modest rises in the quality in silver watches, so that a watch at the 75th percentile in the 1710s was equivalent to one of median

[1] Tim Hitchcock, Robert Shoemaker, Clive Emsley, Sharon Howard and Jamie McLaughlin, et al., The Old Bailey Proceedings Online, 1674-1913 (www.oldbaileyonline.org, version 7.0, 24 March 2012).

quality in the 1770s, we find an annual fall in real prices of 2 per cent or 87 per cent over a century, not far from what Adam Smith suggests.[2]

Most of the cost of a silver watch mechanism was the labour involved in cutting, filing and assembling the parts, so—assuming a constant markup, which is probably valid given the small scale of individual producers and the absence of foreign import penetration before 1815—we can gauge the rise of labour productivity in watch making by comparing how the price of a watch fell relative to nominal wages.[3] During the period 1680–1810 real wages were roughly constant so this rise in labour productivity is similar to the fall in real prices of watches.

To put the productivity growth in eighteenth century watchmaking in perspective, Crafts and Harley (1992) estimate that average labour productivity in British industry grew by 0.26 per cent per year in the period 1759–1801, and 0.21 per cent from 1801–1831, while the corresponding estimates from Broadberry, Campbell and van Leeuwen (2013) are 0.63 and 0.68: see Crafts (2014, Table 3). Scientific and musical instruments aside, watches were the most complex artefacts of their time. This rapid productivity growth in their manufacture stemmed from continuous improvements in tools and techniques and an intensifying division of labour; with watchmaking showing strong spatial concentration and individual artisans specializing in the production of a single interchangeable component, or, more precisely, a component that could be interchanged with another after a judicious amount of filing.

In terms of their wider implications, our results highlight that the process of sustained technological progress long used to define the Industrial Revolution dates back in England to at least the late seventeenth century, rather than the accepted date of the mid-eighteenth century. The evolution of the English watch industry also supports the view of Kelly, Mokyr and Ó Gráda (2014) on the importance of the interaction between elite inventors and skilled artisans as one source of the Industrial Revolution. The decisive innovation in making portable watches reasonably accurate was the balance spring associated with two of the greatest scientists of the late seventeenth century: Robert Hooke probably came up with the idea of replacing a pendulum with a spring in 1658, and Christiaan Huygens made the first working spring watch in 1675 (Landes, 1983, 124–128). Once this conceptual breakthrough occurred, England's extensive tradition of metal working and the relative absence

[2] Because watches fulfilled a variety of purposes, being status symbols and stores of value as well as ways to tell the time accurately, we cannot come up with some simple quality adjusted measure of cost such as the price per lumen-hour of lighting derived by Nordhaus (2008).

[3] The use of price falls to infer the rate of productivity growth was pioneered by McCloskey (1981). See also Antràs and Voth (2003), Clark (2007, 273–278) and Hsieh (2002).

of restrictions on hiring apprentices, along with an extensive market of affluent consumers, allowed its watch industry to expand rapidly.

Regarding technological spillovers, the role of watch and clock makers in designing and building the textile machinery of the early Industrial Revolution is probably overstated. Its real technological contribution lies rather in its close connection with an equally innovative and overlooked sector of the British economy: instrument making. The advances in steam engines and machine tools in the late eighteenth century—what we may call the High Industrial Revolution to distinguish it from the Low Industrial Revolution in cotton and wrought iron that, although important for output and employment, largely represented technological dead ends—would have been impossible without the precision lathes and measuring tools that developed steadily from the late seventeenth century to produce scientific and navigational instruments.

Whereas the sole focus of most modern studies of the Industrial Revolution is on the incentives to innovate, these incentives have existed throughout human history. The history of watchmaking highlights instead the inescapable importance of developing the capacity to innovate, with Britain coming to possess unique skills in precision metalworking on a scale that existed nowhere else in Europe, let alone the Middle East, India, or China.

By the late eighteenth century, the English watch industry was producing around 200,000 watches per year, about half of European output (Landes, 1983, 231), while watch ownership was high, even among labourers, as we will see below. However, the British watch industry was precocious not only in its rise, but in its fall. By the 1820s, the English watch industry had reached the limits of its technical and organizational ability and was starting to face severe competition from cheap Continental imports, leading to considerable hardship in traditional watchmaking areas and petitions for import controls.

Although there is an extensive literature on the history of time keeping (for instance Britten 1934 and Landes 1983) its emphasis is on expensive watches and chronometers rather than the mass produced watches that are our concern here. The rise of the English watch industry is described by Cipolla (1970, 141–147), Thompson (1967, 64–70), and Landes (1983, 231–235); and the widespread ownership of watches by the end of the eighteenth century is demonstrated by de Vries (2008, 2–3) and Styles (2007, 98–107). The Old Bailey records have not been used before to track prices, but were used in the pioneering study of Voth (2001) to estimate changes in people's time use (based on witnesses reports of what they were doing, working or at leisure, at the time a crime was committed, which requires the widespread ownership of watches to establish time of day reliably). More recently Horrell, Humphries and

Sneath (2015) have used Old Bailey records to look at changing patterns of ownership of consumer goods.

The rest of the paper is as follows. In Section 2 we outline our data on watch prices from the Old Bailey, while Section 3 analyses the fall in watch prices during the eighteenth century. Section 4 demonstrates that the observed falls in watch prices are not caused by the appearance of more low quality watches in the sample, but reflect rising productivity. The evolution of watch prices during the early nineteenth century is examined in 5. Section 6 briefly outlines the organization and functioning of the English watch industry and Section 7 discusses the implications of our results for the wider understanding the Industrial Revolution.

2 Watch Prices in the Records of the Old Bailey.

We use records of criminal trials in the Old Bailey to track the path of watch prices from the late seventeenth until the mid-nineteenth century. Because watches were valuable and easily resold, organized theft of watches was widespread (Thompson, 1967; Linebaugh, 2003, 225–227). Court records give the reported value of 7,273 stolen watches running from 1675 to 1850 but early observations are sparse, with only 92 records before 1710. Contemporaries divided watches into two types: utilitarian metal or silver watches, and more expensive gold ones: for instance, in 1797–98 the British government imposed a tax on watch ownership, with a rate of 2.5 shillings for a silver watch, and 10 shillings for a gold one (Thompson, 1967, 67).

After 1809, all but 103 of the 4,027 watches in court records are described simply as "watch". Before this, however, more detail is provided. For the 3,246 stolen watches before 1810, 61 per cent are described simply as "silver watch" and 9 per cent as "gold watch". The distribution of watches by type is shown in Figure 1.

The fact that our data come from criminal trials may bias our sample towards more expensive watches. Before 1829 London did not have a regular metropolitan police force, so that most prosecutions for theft were privately initiated: useful descriptions of the evolution of London's criminal justice system during this period are given by Friedman (1995) and Voth (2001). This may bias our later data towards wealthier victims with more expensive watches.

During the 1720s, the normal daily wage for a building labourer in London was 3 shillings, equivalent to £0.9 for a six day week.[4] Looking at the silver watches

[4]This is based on Hunt (1986, Table 5) who gives a wage of 3 shillings per day for the 1760s, and Clark (2005) who shows that nominal wages hardly changed between the 1720s and 1760s. Clark's data are available at http://gpih.ucdavis.edu/files/England_1209-1914_(Clark).xls

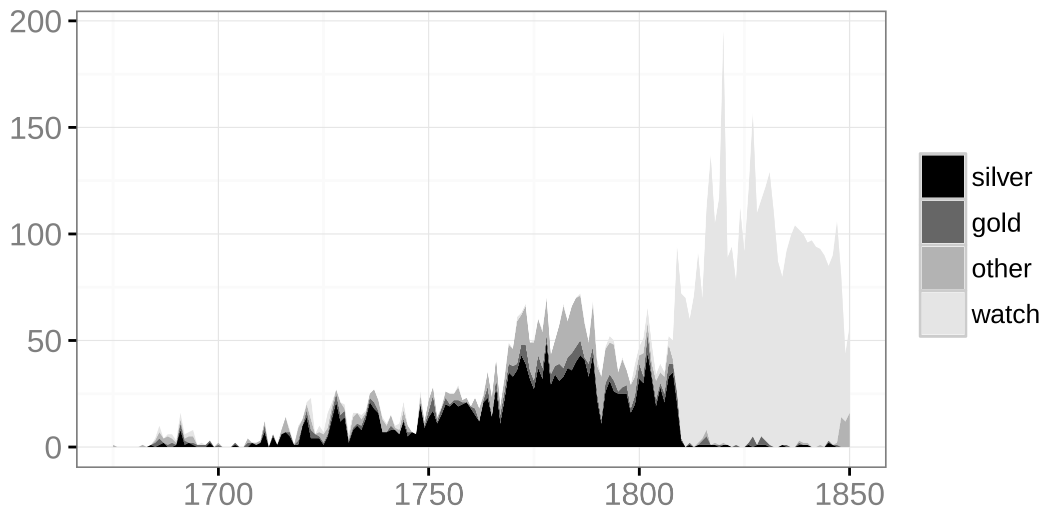

Figure 1: Annual number of watches in Old Bailey records by type.

in our records from the 1720s, the median value was £4, the first quartile is £2.5, and the cheapest watch was £1: in other words, watches were expensive relative to wages, making it likely that most thefts would have been prosecuted. By the 1790s, however, nominal wages had risen to 3.5 shillings per day, or £0.95 per week, whereas the median and bottom quartiles of watch values have halved to £2 and £1.25 respectively. There is therefore a likelihood that in later periods, thefts of cheap watches may not have been worth the effort of prosecution, but when we control below for possible sample censoring, the impact on estimated price falls is negligible.

2.1 Social Status of Victims.

A sense of who owned watches on the eve of the Industrial Revolution may be obtained from Table 1 which gives the average value of watches (in 1750 prices) and the share of the sample of victims whose social status may be guessed at for selected time periods. "Gent." describes victims who are described as gentlemen, traders, clerks, travellers by coach or on horseback, homeowners, and other obviously affluent individuals; and "Lab." refers to victims who are described as artisans, labourers, servants or lodgers. "Drunk" refers to victims not in the other two categories who admitted to having their watches stolen in a tavern or by a prostitute, typically at

	Average Value			Percentage			
	Gent.	Lab.	Drunk	Gent.	Lab.	Drunk	N
1710–1729	10.00	3.05	5.05	61.30	7.10	31.60	155
1730–1739	8.90	4.70	3.90	54.30	11.70	34.00	94
1740–1749	8.11	2.95	4.11	40.50	26.20	33.30	84
1750–1759	4.46	2.38	2.87	38.40	39.10	22.50	151
1780–1784	4.65	2.05	1.81	47.50	36.90	15.60	301
1800–1803	2.63	1.40	1.52	38.90	51.40	9.70	185

Table 1: Average value of watches for different groups of victims in selected periods; the percentage of each group in the sample; and the total number of victims.

night and in disreputable parts of the city. This last group is also likely to have been of lower status: for example in 1780–1784, 13 of the artisans were also in the drunk/prostitute category, but only 5 of the gentlemen, and the numbers are similar for other periods.[5]

The table shows that watch ownership among working men rose steadily through the eighteenth century, and had become extensive by 1800, something also found by Styles (2007, 98–107). Moreover, the value of watches for every group falls steadily through time (the apparent rise for artisans in the 1730s is caused by a single expensive watch); with gentlemen predictably owning more expensive watches than labourers.

3 Watch prices, 1710–1809.

As Figure 1 shows, the generic watch in the Old Bailey records before 1810 is a silver watch. Figure 2 plots the reported value of a ten per cent sample of silver watches in 1750 prices (deflated using Clark's (2005) retail price index). Points are jittered to separate overlapping values, and the figure includes a locally weighted sum of squares (loess) line to indicate trends. Three outliers are omitted to make the plot more legible: two watches valued at £20, and one valued at £0.10. Distinct lines appear in the diagram, reflecting the fact that watch prices heap around integer

[5]In 1744 the trial judge observed to a young man who had his gold watch pickpocketed in a laneway off the Strand that "It was an odd thing for a young gentleman to pick up a woman in the street, and was sober when you went about such a scandalous practice." [http://www.oldbaileyonline.org/browse.jsp?id=t17440510-7&div=t17440510-7#highlight].

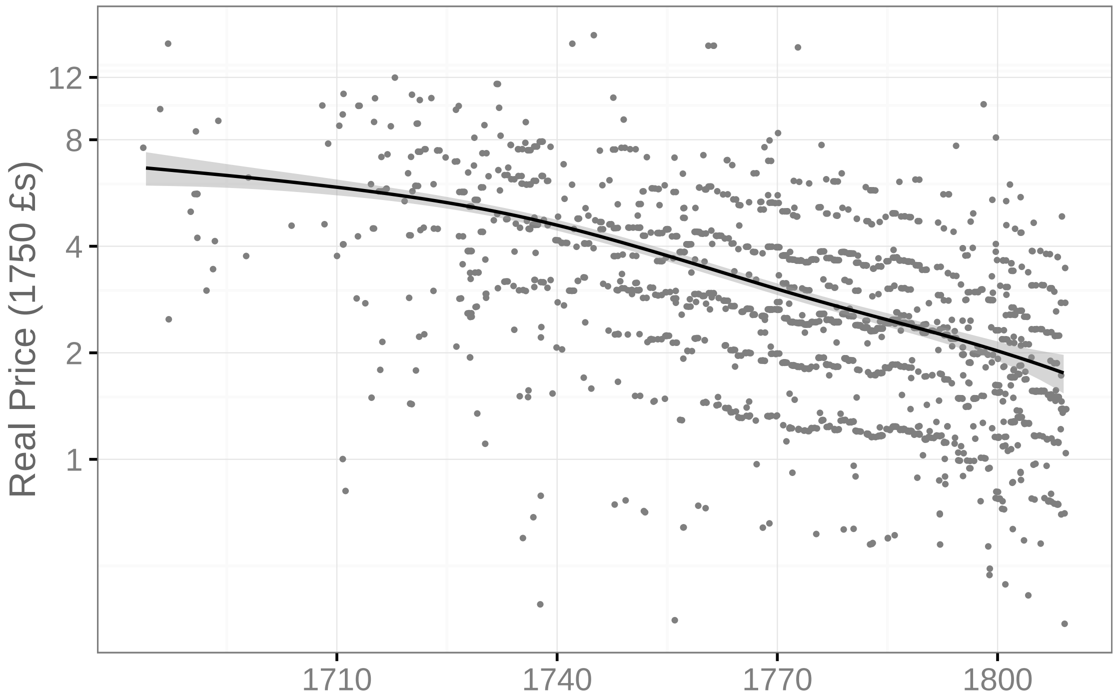

Figure 2: Reported value of silver watches (in 1750 pounds, logarithmic axis) in Old Bailey trials, 1680–1809.

values. It can be seen that the average price of a silver watch falls from around £6 in 1710 to about £2 by 1809.

Table 2 gives the results of a regression of the log of silver watch prices (again deflated to 1750 prices) on year from 1710 to 1809. It can be seen that the price of silver watches falls at 1.3 per cent per year.

A potential problem is the absence of very cheap watches from court records by the end of the eighteenth century. We therefore include in Table 2 estimates for the fall in watch prices under two semiparametric estimators that control for sample truncation: Symmetrically Truncated Least Squares (Powell, 1986) and a Left Truncated estimator (Karlsson, 2006).[6] It is assumed that watches valued below 4 shillings (£0.2) are excluded—increasing this threshold did not alter the results materially. It can be seen that controlling for truncation has almost no impact on the estimated price falls.

[6]These are calculated with the R package truncSP (Karlsson and Lindmark, 2014).

	Silver			Gold
	OLS	TSLS	LT	OLS
(Intercept)	24.2449	24.2449	25.2580	25.4240
	(0.9186)	(0.8849)	(2.1247)	(2.8221)
Year	-0.0131	-0.0131	-0.0136	-0.0129
	(0.0005)	(0.0005)	(0.0012)	(0.0016)
R^2	0.2837			0.1956
N	1950			281

Watch prices are in 1750 pounds. Standard errors are in parentheses. TSLS denotes Symmetrically Truncated Least Squares estimates, and LT Left Truncated ones. OLS regressions report heteroskedastic consistent standard errors.

Table 2: Regressions of log silver and gold watch prices on year, 1710–1809.

There were two parts to a watch: the mechanism or movement which was mostly brass with a steel spring; and the protective case. It would be expected that most of the fall in the cost of a watch would be in the mechanism, and this will be understated if the case is included. This turns out not to make much difference, however.

A cheap double cased watch of this period contained roughly two ounces of silver, and more expensive watches perhaps two and a half.[7] During our period the value of a pound sterling remains around 3.8 ounces of silver, so that the silver content of a watch case would have been around 5 shillings. Subtracting this amount from the declared value of watches causes the real price of mechanisms to fall at 1.5 per cent per year, compared with 1.3 per cent for complete watches.

As noted in the Introduction, the production cost of a basic watch was largely the labour involved in cutting, filing and assembling the parts, so the growth of productivity may be assessed by comparing watch prices with wages. From 1710 to 1810 real wages, measured by Clark's (2005) series, were roughly constant, which means that shifts in demand for watches associated with rising incomes can be ignored. We find an annual fall of watch prices relative to nominal wages of 1.4 per cent, compared with 1.3 per cent relative to prices.

However, national wage series disguise considerable regional variation. Much of the production of watch parts was concentrated in Lancashire which, with the rise of the cotton industry, went from one of the lowest wage parts of England in the 1760s

[7] *Monthly Magazine*, 47, 1819. There may also have been a long-term decline in the thickness, and therefore the silver content, of watch cases with the introduction of roller flattening to produce silver sheet from the 1720s (Clifford, 1999). We are grateful to John Styles for this information.

to one of the highest by 1833 with nominal wages increasing 40 per cent relative to national prices (Kelly, Mokyr and Ó Gráda, 2015). Given this strong rise in labour costs, it seems likely that price falls will understate productivity growth in the late eighteenth century watch industry.

4 Sample composition.

The findings in Table 2 that watch prices fell by around 1.3 per cent per year will be a misleading indicator of productivity growth if the composition of the sample changes through time to include more cheap, low quality watches. Suppose, for instance, that no technological progress occurs, and that there are two types of watch whose price remains fixed through time: high quality watches with average price μ_h and low quality ones with average price μ_l. However both are described in court records as "Silver Watch". Let w be the unobserved fraction of low quality watches in the court records, and suppose that this increases through time, reflecting the increasing affluence of ordinary workers. It follows that the average price of "Silver Watches" $(1-w)\,\mu_h + w\mu_l$ will fall as time passes, giving a downward sloping regression line.

There are three ways to check whether our results are driven by such a changing sample composition. The first check is to look at how the different quantiles of the price distribution evolve through time. Intuitively, if the sample contains an increasing share of low quality watches, lower price quantiles will fall faster than higher ones. In all periods the top quantiles will be dominated by the highest quality watches so that their price will barely fall, but the lowest quantiles will increasingly be dominated by the worst low quality watches, and will show the largest price falls. Secondly, we can compare price falls for silver watches with those for gold watches, a category that remains affordable only to the very rich where we can be certain that sample contamination by low quality timepieces is not an issue.

Looking first at the quantiles of the price distribution, if there is only one quality of watch all quantiles will fall at similar rates, whereas if cheaper watches appear, different quantiles will fall at different rates as time passes. In the Appendix we show that, with two types of watch, the price of cheap watches will always fall faster than dearer ones for quantiles above the share of low quality watches w. Below w the quantiles of cheaper watches will fall fastest if the slope of the quantile function for high quality watches is less than $1/\,(1-w)$ times the slope for low quality ones.

The time series of watch prices in Figure 2 suggests that the price fall was fairly uniform across all price ranges, and this can be confirmed with a quantile regression (Koenker, 2005). Figure 3 gives the slope coefficients and 2 standard error confidence

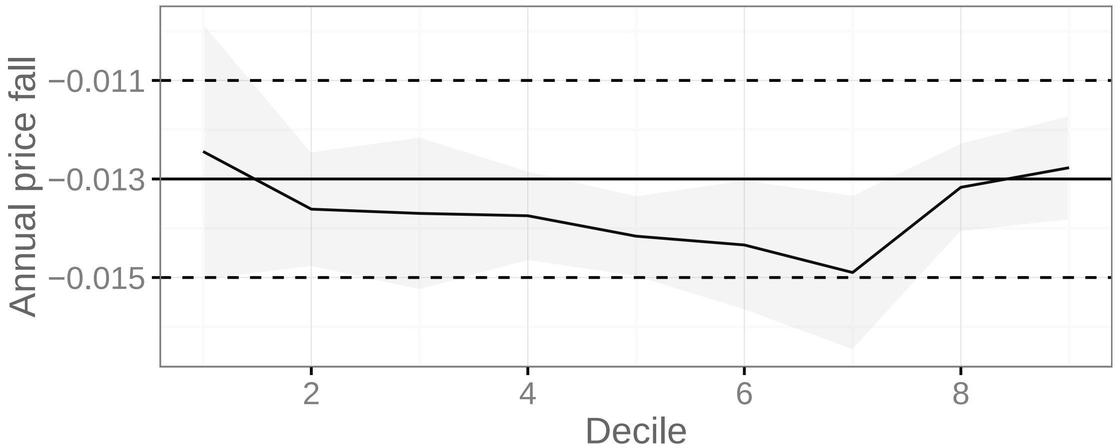

Figure 3: Annual price fall from quantile regression of silver watch prices, 1710–1809. The horizontal line denotes the coefficient and confidence intervals for the entire sample. .

interval for each decile of the data.[8] We can see that, although mid-price watches show a slightly larger yearly fall of 1.4 per cent, there is little variation around the average 1.3 per cent annual fall. It is notable that this fall is close to that estimated by Elmers (1992), who suggests that the price of good quality London pair-case silver watches—a homogeneous category, in other words—fell from about £8.5 in 1710 to around £2.5 by 1810, or 1.2 per cent per annum.

As a second check for potential composition effects, we can compare the observed price falls of silver watches with those of gold watches, which remain luxury items affordable only to the wealthy. For the 280 gold watches in the court records,[9] the last column of Table Table 2 on page 9 shows that the price of gold watches falls at the same rate as silver ones.

A final, informal, check comes from Table 1 giving the value of watches belonging to different social classes through time. It shows how the average value of watches for both the affluent and labourers—again more homogeneous samples—fall steadily through the eighteenth century.

[8]These are calculated with the R package quantreg. Standard errors are estimated using the wild bootstrap of Bilias, Chen and Ying (2000): using other bootstrap procedures gave similar results.

[9]We exclude one gold repeater watch with a reported value in 1764 of £630: for comparison, at the time, the cost of building a Royal Navy sloop, before fitting with guns, was around £1,800 Winfield (2007, 310–311). The next most expensive watches in our sample are two worth £100.

It appears then that the observed price fall in silver watches is not caused by changing sample composition but reflects real rises in productivity stemming from improved technology and intensified division of labour. These estimates of real price falls of around 1.3 per cent per year will, of course, be under-estimates of productivity growth in watchmaking if, as seems likely, the quality of watches rose through time. It is to be expected that more accurately shaped parts made from harder metals would increase both the durability and accuracy of watches.

In summary, Adam Smith's claim that nominal watch prices had fallen by 95 per cent in the previous century is clearly something of a rhetorical exaggeration: the implied fall of 3 per cent per year is higher than the 2.6 per cent rise in real productivity that McCloskey (1981) estimates for the most dynamic industrial sector, cotton, from 1780–1860. For Smith's claim of a 3 per cent fall to be true, a watch that cost £1 in the 1770s would have had to cost £6 sixty years earlier in the 1710s. Looking at our sample of silver watches, this would imply that a watch at the 80th percentile of quality and price in the 1710s would be equivalent to one at the tenth percentile in the 1770s, which seems implausible. If, however, we suppose conservatively that a watch at the third quartile of quality in the 1710s was equivalent to one at the median by the 1770s, we get an annual fall in real price of 2 per cent, or 87 per cent over a century.

5 Watch Prices, 1810–1850.

After 1810, as Figure 1 shows, most watches in the Old Bailey records are described simply as "watch". Figure 4 shows a ten per cent sample of the declared value of all 7,192 watches (excluding the £630 one) in the Old Bailey records from 1700 to 1850. It can be seen that the average price of all watches before 1810 shows the same behaviour as the subsets of silver and gold watches looked at above, but with a slightly higher rate of fall, decreasing by around four fifths in real terms between 1700 to 1810. However, prices reach a minimum in the 1810s and then start rising steadily until 1850.

This price rise in the court records appears driven by two factors. First, the cases tried at the Old Bailey change markedly at this time, with an increasing number of minor thefts being prosecuted in Local Sessions (Feeley and Little, 1991, 724–725), so the Old Bailey sample is no longer a reliable guide to average watch prices. For instance, despite frequent contemporary references to cheap imported watches costing 5 shillings, our sample of over 4,000 watches from this period lists only 16 of these. Secondly, as Landes (1983, 274–307) and Davies (1992) demonstrate, the English watch industry was technologically conservative compared with its Swiss and,

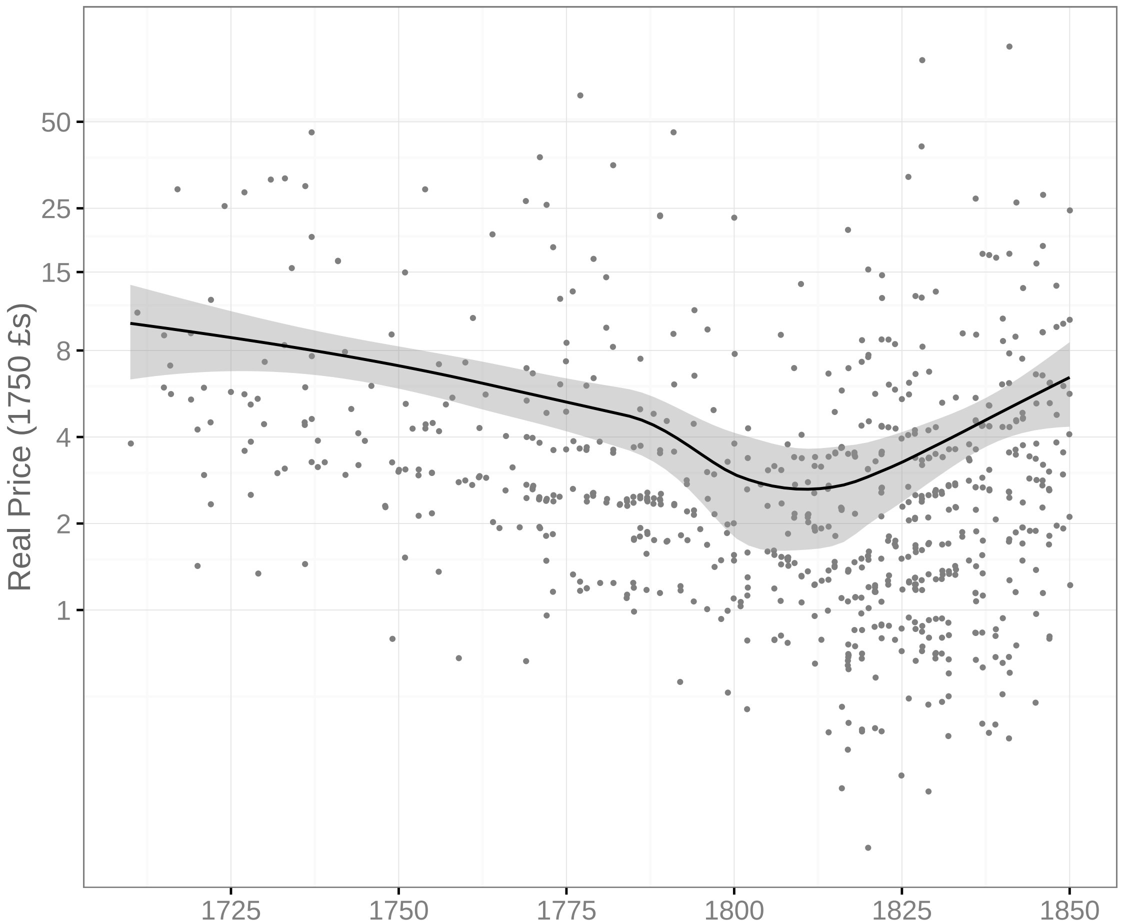

Figure 4: Reported value (in 1750 pounds, logarithmic axis) of all stolen watches in Old Bailey trials, 1700–1850.

later, American rivals, and had reached the limits of technological improvement and division of labour under its fragmented organization before 1815. As real wages rose in England (by around 50 per cent in Clark's series from 1810 to 1850), production costs were driven upwards, while the rising affluence of consumers probably increased demand for more expensive watches.

As we did for silver watches before 1810, we can examine whether a changing composition of watches in court records is driving these observed price changes by looking at the quantiles of the price distribution. Figure 5 shows the result, by decile,

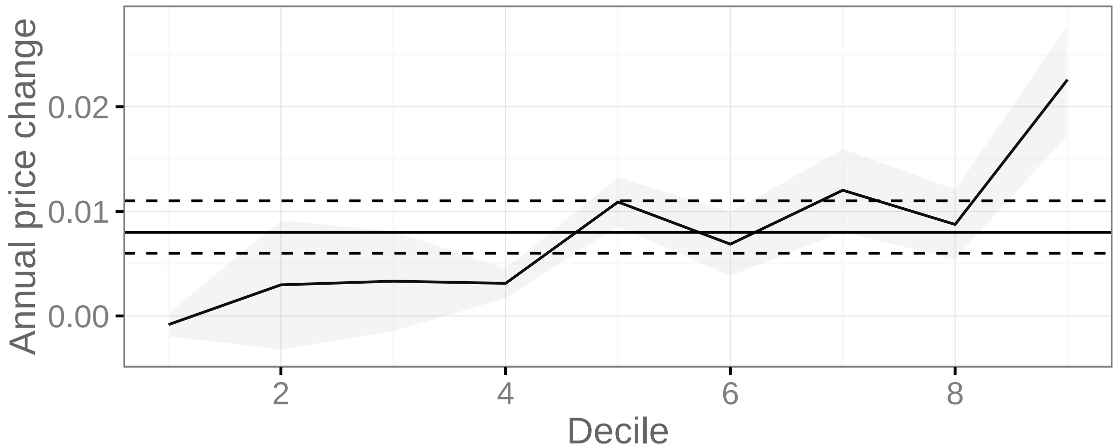

Figure 5: Annual price rise from quantile regression of all watch prices, 1810–1850.

of a quantile regression of log price on time. In contrast to the pre-1810 sample of silver watches, watch prices now diverge sharply as time passes. The price of the cheapest watches remaining roughly fixed whereas the cost of the most expensive ones rises by over 2 per cent each year. This indicates that the composition of watches in the court records is shifting to include a larger proportion of high quality watches, meaning that observed price changes are no longer a reliable guide to productivity changes in the sector.

6 The Evolution of the English Watch Industry.

This steady fall in watch prices from the late seventeenth century until around 1810 reflects the continuous technological innovation and increasingly minute division of labour of the English watch industry. The first portable, spring driven time pieces—watches in other words—appeared in Germany around 1500, and the first English ones were made by French and German immigrants in London about a century later. However it was not until the invention of the balance spring by Robert Hooke or Christiaan Huygens around 1660 that watches became sufficiently accurate to be of practical use. Cipolla (1970, 143) estimates that by 1680, in terms of output and innovation the English watch industry had become dominant in Europe.

Although largely overlooked in most histories of the Industrial Revolution, time pieces, and pocket watches in particular, represent the first mass produced consumer durable as de Vries (2008, 2–3) demonstrates. Clocks and watches are mentioned in fewer than 10 per cent of English probate inventories around 1675, but in over a third by the 1720s, and appear in nearly 40 per cent of pauper inventories for the period 1770–1812. Looking at the wills of servants in Paris, 13 per cent already mention watches by 1700, and this rises to 70 per cent by the 1780s; and the corresponding figures for the wills of wage earners are 5 and 32 per cent.

Watches fulfilled a variety of functions. Naturally, they told the time more or less accurately, something that became more important as urbanisation grew and economic activity intensified, increasing the need for coordination between people. Watches were visible status symbols, but also, in an era before mass banking, served as convenient stores of value: a windfall could be used to buy a watch that could later be sold or used as collateral to borrow from a pawn broker (George, 1966, 363; de Vries, 2008, 3).

Widespread watch ownership implied large scale production, and by the last quarter of the eighteenth century western Europe was producing about 400,000 watches a year, nearly half of them in England (Landes, 1983, 231). Based on the expected revenue yield of the 1797–98 watch tax, Thompson (1967, 68) estimated that the government believed there to be 800,000 silver and metal watches, and 400,000 gold ones; while Voth (2001, 51) estimates that, depending on how long one assumes an average watch lasted, there were from 1.4 to 3.1 million watches in England around 1800, or one watch for every 1.8–4 adults.

Unlike clock production, which was widely diffused across England, watchmaking was highly spatially concentrated, centred on London, Coventry, and around the town of Prescot near Liverpool. Production was organized as a cottage industry where parts were made by specialised artisans, and then assembled into mechanisms. Finally the mechanisms were finally fitted into a case with a faceplate that bore the name of the watchmaker who arranged and financed the entire process, and marketed the finished product. The first specialized trade was spring making, but division of labour was extensive by the mid-eighteenth century George (1966, 175–177), and by the early nineteenth century it had risen to a degree described by a Coventry watchmaker {Great Britain} (1817, 77):

> "Movement maker, is divided into frame mounter, brass flatter, pillar maker, crew maker, cock and pittance maker, wheel maker, wheel finisher, barrel maker, barrel arbor maker, pinion maker, balance maker, verge maker, ratch and click maker, and other small steel work; ...and several other branches to the number of 102 in the whole."

The marriage registers of Prescot, the centre of Lancashire watch-making, happen to list the occupation of the bridegroom, and allow us to assess the educational level of watchmakers from their ability to sign their name.[10] Between 1773 and 1845, 644 colliers, 654 labourers, and 183 watch and watch-tool makers got married in Prescot's St. Mary the Virgin church. Overall literacy was low, and did not rise much through the period with 83 per cent of colliers and 69 per cent of labourers being illiterate. The educational level of watchmakers is higher, but 28 per cent still could not sign their names.

6.1 Contemporary Accounts.

If the production of watches in the early eighteenth was as sophisticated as we are claiming, it should have attracted the attention of observers before Adam Smith, and this turns out to be the case. In what appears to be the first, and certainly the most sophisticated, discussion of the concept before Smith, Martyn (1701, 42–43) used watches to illustrate how the division of labour is limited by the extent of the market: "...if the Demand of Watches shou'd become so very great as to find constant imployment for as many Persons ... the Maker of the Pins, or Wheels, or Screws, or other Parts, must needs be more perfect and expeditious at his proper work, ...than if he is also to be imploy'd in all the variety of a Watch."

In a mid-eighteenth century description of London trades Campbell (1747, 250) described how watches "at their first appearance ... were began and ended by one man who was called a watchmaker" but "of late years the watchmaker ...scarce makes anything belonging to a watch. He only deploys the different tradesmen among who the art is divided..."

As Landes (1983, 231) observes, watchmaking better exemplifies the benefits of specialization than does Adam Smith's pin factory. In fact, in his Introduction to *The Wealth of Nations,* Canaan suggests that Smith (1976, 7) probably got the idea of division of labour from Mandeville's 1729 discussion of watchmaking in *The Fable of the Bees*: "...watch-making, which is come to a higher degree of perfection that it would have been arrived at yet, if the whole had always remain'd the Employment of one person; and I am persuaded, that even the Plenty we have of Clocks and Watches, as well as the Exactness and Beauty they may be made of, are chiefly owing to the Division that has been made of that Art into many Branches."

[10] http://www.lan-opc.org.uk/Prescot/

7 The Industrial Revolution.

We consider some implications of our results on sustained productivity rises in watch making during the eighteenth century for understanding the Industrial Revolution. A widespread view is that the Industrial Revolution represents an acceleration of innovation in cotton spinning and iron making that occurs in England from the middle of the eighteenth century (Crafts and Harley 1992); and, more controversially, that this innovation was induced by the need to economize on the high wages of English workers Allen (2009).

Against the view of a narrowly based Industrial Revolution, our results on watch-making support the view of a more broadly based advance across many manufacturing sectors proposed by Berg and Hudson (1992) and Temin (1997) amongst others. Sectors such as brewing, pottery, glass, hydraulics and mechanical engineering showed signs of technological dynamism in this period: for a survey see Mokyr (2009, 131–144); and more recent research has detailed progress in sailing ships (Kelly and Ó Gráda, 2014) and gas lighting and water supply (Tomory 2012; 2015). Clark (2007, 252–254) observes that there was continuous productivity growth in the production of nails and books in earlier centuries, but what distinguishes watches from these fairly simple commodities is that, excepting scientific instruments, watches were the most complex artefacts of their time, and that is what makes their productivity growth so interesting.

As for timing, our results support the view that the roots of the Industrial Revolution stretch back further than the mid-eighteenth century. The beginnings of growth in the seventeenth century are consistent with the findings of Broadberry et al. (2015) on English GDP (but see Clark 2005 for a more pessimistic view). By the early seventeenth century there occurs not only growing urbanization and an associated intensification of agriculture, but, in the north and west of England, growing regional specialization in mining, metal working, and textile production that supplemented income from agriculture (Clay, 1984, 98–102). In particular, as Bailey and Barker (1969) demonstrate, the origins of watch making in Lancashire lie in the area's tradition of brass making that dates back to the late sixteenth century.

On the demand side, England was a fairly prosperous place by the late seventeenth century, with a large and growing middle class of merchants, prosperous farmers, professionals and successful artisans to provide a large market market for status goods like watches. Without such an extensive market, which tends to be neglected in supply focused accounts of the Industrial Revolution, none of the division of labour and innovation that we have shown here could have occurred.

A widespread view is that heavy population growth coinciding with the early Industrial Revolution led to a stagnation of real wages (Allen, 2007). The fact that, as Table 1 shows, large numbers of working men could afford an expensive status good like a watch would suggest that such pessimism about living standards may be overstated.

The invention of the balance spring by Robert Hooke and/or Christiaan Huygens, and its use by Thomas Tompion—an instrument maker for the Royal Society who went on to be England's greatest watch-maker—to make the first reliable watch, serve as a strong and early example of Mokyr's (2009, 30–62) concept of Industrial Enlightenment: the interaction between elite scientists and talented artisans to develop several important new technologies. The rapid subsequent growth of watch production in England was facilitated by the relative absence of guild restrictions limiting the number of apprentices that could be hired; and the scale of existing cottage industries that provided a large pool of workers with the requisite metalworking and entrepreneurial skills to grasp and develop new business opportunities. A particular advantage of cottage industry is in the rapid diffusion of new techniques: a technological improvement cannot be kept secret as it can within a large firm.

After the balance spring was invented, subsequent improvement is largely driven by these anonymous artisans. Although there are famous watchmakers associated with developments in luxury time pieces and chronometers—described by Britten (1934) and Landes (1983)—the continuous productivity growth in ordinary watches described here stems from the efforts of invisible innovators rather than the Great Inventors who are central to many accounts of British industrialization. This vitality of small scale production in eighteenth century England is also emphasized by Berg and Hudson (1992).

Watchmaking provides a counter-example to the influential view of Allen (2009) that high wages induced British industrialization and productivity growth. The production of watch-parts originated, along with most of the better known innovations of the Industrial Revolution, in one of the lowest wage areas of England (Kelly, Mokyr and Ó Gráda, 2015) and rising productivity led to high wages, rather than the other way around.

Along with specialized lathes, vices, files, and cutting tools, the watch industry was associated with two innovations of sufficient importance to rank as general purpose technologies in the development of British instrument and machine making. The first, from before 1672 and often attributed to Robert Hooke, was the mechanical cutting of gear wheels, which permitted far more accurate and durable mechanisms in watches, scientific instruments, and machines (Bailey and Barker, 1969). The second, by the clockmaker Benjamin Huntsman around 1740, was high quality crucible steel that allowed the production of far superior springs, files, and cutlery than were available elsewhere (the process spread to continental Europe only after 1800).

Because of the uniquely small size and high precision of their components, watch and instrument making did not benefit significantly from advances in other sectors, with two important exceptions. Precise parts required high zinc brass free of chemical impurities. This started to become available in the early eighteenth century with the replacement of coal by coke in copper smelting around 1710; and William Champion's 1738 patent (Number 564) for the distillation of zinc (Pollard and Heron, 2008, 203–204). Secondly, the spread of the cold rolling process from tinplate production to other metals by the early eighteenth century allowed the production of brass plate of uniform thickness allowing blanks to be stamped at lower cost before cutting into gear wheels which were of more uniform quality.

In discussing the first Industrial Revolution, a lot of confusion can be avoided by distinguishing between the largely empirical advances in cotton and iron—what we may call the Low Industrial Revolution—and the more scientifically based High Industrial Revolution in steam and machine tools.

Because the Lancashire watch parts industry was located in the same part of England that subsequently developed mechanical cotton spinning, it is sometimes cited as an example of technological diffusion: this was the opinion of several witnesses to the House of Commons Great Britain (1797, 331, 335), echoed by Foster and Jones (2011). However, we should be cautious of overly simplistic stories of technological spillover. It was certainly the case that the presence of large numbers of artisans accustomed to making and improving mechanisms, and easy access to high quality gears and springs, aided the builders of early textile machinery. However, the very different size and forces experienced by an iron machine compared with a brass clock or watch caused machine building rapidly to become a separate and specialized activity; and the painstaking study of Cookson (1994, 51–77) finds that most of the early textile machine builders in West Yorkshire had backgrounds in metal working rather than clock making.

The central contribution of watch and clock making to the wider Industrial Revolution lies rather in its close connection—in materials, techniques and personnel—with another dynamic and neglected sector of the late seventeenth and eighteenth century British economy: instrument making. The need for increasingly exact scientific and navigational instruments drove the continuous development of precision lathes and measuring instruments that permitted the construction of efficient steam engines (Watt was trained as an instrument maker, and his partner Boulton was a friend of Jesse Ramsden, the greatest instrument maker of the eighteenth century), and formed the basis of the nineteenth century machine tool industry: the key sectors of the High Industrial Revolution.

While our focus has been on the implications of the rise of the English watch industry for understanding the Industrial Revolution, its subsequent decline is also revealing. High wages made England's watch industry vulnerable to cheap continental imports, with English wages twice those in Zurich in 1815 (Studer, 2008, Table 2). By the 1830s cheap Swiss watches had replaced English watches across much of Europe and perhaps 8,000–10,000 were being smuggled into the United Kingdom annually, with perhaps several times that number in the 1840s before the reduction of tariffs that started in 1850 (Rees 1819; Bowring 1836; Davies 1992, 98).[11]

Whereas a simple Ricardian model would predict English watchmakers relocating smoothly to other sectors, the decline of the watch industry is more suggestive of entrepreneurial failure; being associated with considerable unemployment, falling wages, and hardship in traditional manufacturing areas like Prescot and Coventry detailed in contemporary Parliamentary reports. At the same time, although the Allen (2009) model would predict that high wages should have induced a burst of labour saving innovation in British watch-making, the sector in fact remained organisationally and technically conservative, being decisively overtaken by more innovative Swiss and American competitors as the nineteenth century progressed, a process outlined by Landes (1983, 257–320).

8 Conclusions

The Industrial Revolution has long been defined as the start of systematic innovation in cotton and iron making that begins around the middle of the eighteenth century. In this paper, by contrast, we focused on watches, a sector absent from modern discussions of the Industrial Revolution, but, for Adam Smith the pre-eminent example of technological progress.

To evaluate Smith's claim that watch prices had fallen markedly over the preceding century we analysed records of criminal trials at the Old Bailey, which give the value of stolen watches, and found steady falls in price for all categories of watch of around 1.3 per cent per year. Our results show that the continuous technological improvement and intensification of division of labour, usually dated to the mid-eighteenth century, goes back to at least the late seventeenth century, and

[11] In 1827, the earliest year with detailed official trade data, official clock and watch imports, paying a duty of 25 per cent, were £15,000; whereas exports of watches are not given a separate listing, but included along with plate and jewellery which total only £3,200 (Marshall, 1833).

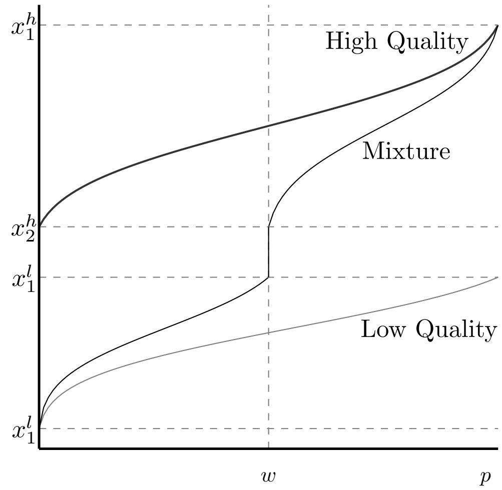

Figure 6: Price quantiles of high and low quality watches, and a mixture with fraction w of low quality watches.

highlights the central role in innovation of the interaction between elite inventors and anonymous artisans. In addition, Britain enjoyed several advantages—a large middle class market, the absence of guild restrictions on numbers of apprentices, and as Kelly, Mokyr and Ó Gráda (2015) find for other expanding sectors, the presence of a large and low wage cottage industry sector with the necessary technical skills for production—that allowed the rapid expansion of the sector.

For the Low Industrial Revolution in cotton and iron, the contribution of the extensive watch industry is negligible; but the skills developed in this sector were vital in the related field of instrument making, another area of British dominance. Without the precision lathes and measuring instruments that originate in these sectors, the steam power and machine tools of the High Industrial Revolution would not have been possible.

Appendix: Quantiles of Mixture Distributions.

Assume that there are two sorts of watches, high quality ones whose (log) price falls in the range $[x_h^1, x_h^2]$ and low quality ones whose price is in the range $[x_l^1, x_l^2]$ where $x_l^2 < x_h^1$ so that the supports do not overlap. Let a watch of quality i have a differentiable distribution function $F_i(x)$ and associated quantile function $G_i(p) =$

$F_i^{-1}(x)$ with slope $g_i(p)$. It follows (Castellacci 2012) that a mixture of high and low quality watches with share w of low quality watches has quantile function

$$G_m(p) = \begin{cases} G_l\left(\frac{p}{w}\right) & p \in [0, w) \\ G_h\left(\frac{p-w}{1-w}\right) & p \in [w, 1] \end{cases} \tag{1}$$

The price quantiles of high and low quality watches, along with a mixture of the two, are shown in Figure 6.

The question asked in the paper is what happens to the quantiles of prices when cheap watches appear: the share of cheap watches w is initially zero so that the price quantile corresponds to the top, high quality line. Through time the share of cheap watches rises, leading to the mixture quantile in Figure 6. For high quantiles of the distribution where $p > w$, the fall in the quantile through time is diminishing in p: the highest quantiles show the smallest falls. This occurs because, from (1), above w the mixture quantiles lie below the high quality one for $p < 1$ and have a steeper slope $g_m = g_h/(1-w)$. For quantiles below w the gap between the quantiles of the high quality watch and the mixture may rise or fall with p. The gap will fall with p at values of p where the slope of the high quality quantile is lower than that of the mixture quantile $g_h(p) < g_m(p) = \dfrac{1}{1-w} g_l(p)$. For a given w this is more likely to occur the smaller is the size of high quality price range $G_h(w) - x_1^h$ relative to the low quality price range $x_l^2 - x_l^1$.

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