# Linear regression

120 marks

Hints online, answers free with an account: mathswariz.uk/worksheets/a-level-statistics-linear-regression/

Date



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## A Do Now

Quick questions to start. Some use earlier lessons; some set a slip that costs marks.

**A1** Needed today [2 marks]

A scatter diagram of the age of a tree, $x$ years, and its height, $y$ metres, shows strong positive correlation. Interpret this in context.

**A2** Needed today [3 marks]

A straight line passes through the points $(2, 11)$ and $(6, 23)$. Find its equation in the form $y = a + bx$.

Answer .....

**A3** Needed today [2 marks]

For the line $y = 4.2 + 0.8x$, find $y$ when $x = 7.5$, and the change in $y$ when $x$ increases by $5$.

Answer .....

**A4** Common slip [2 marks]

The cost, £$c$, of printing $n$ thousand leaflets is modelled by $c = 15 + 2.4n$. Find the cost of printing $40\,000$ leaflets.

Answer .....


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**A5** Common slip [2 marks]

A regression line of $y$ on $x$ is found from data with $x$ from $10$ to $50$. Mo uses it to estimate $y$ when $x = 35$ and when $x = 80$. For each, say whether it is interpolation or extrapolation, and which estimate is reliable.


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## B Example, then your turn

Your teacher works through each example with you. Then try the one beside it.

**EXAMPLE 1**

A café records the daily maximum temperature, $t$ °C, and the number of cold drinks sold, $d$, on $20$ days with $t$ from $12$ to $30$. The regression line of $d$ on $t$ is $d = 18.4 + 6.25t$. (a) Interpret the value $6.25$. (b) Interpret the value $18.4$, and say whether it makes sense.

**Hint** $b$ is the change in $d$ for each $1$ °C rise in $t$. $a$ is the value of $d$ when $t = 0$: is $t = 0$ inside the data?

**B1** [4 marks]

For $25$ students, the regression line of the mark in a test, $s$ %, on the hours of revision, $r$, is $s = 31.5 + 4.2r$. The hours of revision range from $2$ to $15$. (a) Interpret the value $4.2$. (b) Interpret the value $31.5$, and say whether it makes sense here.



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**EXAMPLE 2**

A block of ice melts. Its mass, $m$ grams, $t$ minutes after it is taken out of the freezer is modelled by $m = 480 - 6.4t$, for $0 \leq t \leq 40$. Find the change in the mass of the ice in $15$ minutes.

**Hint** The change over $15$ minutes is $15$ times the gradient. Putting $t = 15$ into the line gives the mass at $15$ minutes, not the change.

**B2** For a model of car, the value, $p$ (£ thousand), of a car aged $a$ years is modelled by the regression line $p = 21.6 - 1.85a$, for $1 \leq a \leq 8$. (a) Interpret the value $-1.85$. (b) Find the change in the value of a car between age $2$ and age $6$. [4 marks]


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**EXAMPLE 3**

For $30$ fish of one species with lengths, $l$ cm, from $18$ to $45$, the regression line of mass, $w$ grams, on length is $w = -312 + 24.5l$. (a) Estimate the mass of a fish of this species that is $0.3$ m long. (b) Explain why the line should not be used for a fish $10$ cm long.

**Hint** Check the units of $l$ before you substitute. For (b), work out the value and look at the data range.

**B3** For $40$ trees with trunk diameters, $d$ cm, from $10$ to $60$, the regression line of height, $h$ metres, on diameter is $h = 1.2 + 0.35d$. (a) Estimate the height of a tree with a trunk diameter of $0.4$ m. (b) Explain why the line should not be used for a tree with a trunk diameter of $150$ cm. [4 marks]


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**EXAMPLE 4**

For $12$ adults with heights, $h$ cm, from $150$ to $190$, the regression line of mass, $w$ kg, on height is $w = -94 + 0.95h$. (a) Estimate the mass of an adult who is $170$ cm tall. (b) Nina wants to estimate the height of an adult with mass $60$ kg. She rearranges the line. Explain why she should not.

**Hint** The line of $w$ on $h$ is chosen to make the errors in $w$ as small as possible. Which variable must be the response variable for Nina's estimate?

**B4** [4 marks]

For $20$ students who studied for $5$ to $30$ hours, the regression line of the test mark, $m$, on the hours of study, $s$, is $m = 12 + 1.6s$. (a) Estimate the mark of a student who studied for $20$ hours. (b) Jess rearranges the line to estimate the hours of study of a student who scored $60$. Explain why this is not appropriate.


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**EXAMPLE 5**

Ola measures the height, $y$ cm, of a plant every two weeks. Use your calculator to find the regression line of $y$ on $x$, where $x$ is the number of weeks, and estimate the height after $7$ weeks.

| $x$ (weeks) | $y$ (cm) |
|---|---|
| 2 | 5.1 |
| 4 | 8.9 |
| 6 | 13.2 |
| 8 | 16.8 |
| 10 | 21.1 |
| 12 | 24.9 |

**Hint** Use the statistics mode for two variables, with $x$ in the first list. Give $a$ and $b$ to $3$ significant figures.

**B5** A pool records the noon temperature, $x$ °C, and the number of visitors, $y$, on $6$ days. (a) Use your calculator to find the regression line of $y$ on $x$. (b) Interpret the gradient. (c) Estimate the number of visitors on a day when the noon temperature is $22$ °C. [4 marks]

| $x$ (°C) | $y$ |
|---|---|
| 15 | 62 |
| 20 | 70 |
| 25 | 81 |
| 30 | 88 |
| 35 | 99 |
| 40 | 106 |

Answer .....


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**C1** A ball is dropped from a bridge. Its height above the river, $h$ m, is recorded at times $t$ seconds from $0.5$ to $2.5$, and the regression line is $h = 9.6 - 1.28t$. Asked to "interpret the gradient", Ria writes: "$-1.28$: there is negative correlation." Explain why this scores no marks, and write a full interpretation. [4 marks]


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**C2** The area, $A$ cm², of a patch of mould $d$ days after it is first seen is modelled by $A = 2.8 + 0.45d$, for $1 \leq d \leq 14$. Sam is asked for the increase in the area over $6$ days. He writes: "$A = 2.8 + 0.45 \times 6 = 5.5$, so the area increases by $5.5$ cm²." Explain Sam's mistake and find the correct increase. [4 marks]

Answer .....


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**C3** For $15$ animals of one species, the regression line of body length, $l$ cm, on girth, $g$ cm, is $l = 4.6 + 0.82g$, with $g$ from $14$ to $26$. Find the estimated length of an animal with girth $20$ cm. Tom wants the girth of an animal that is $17.3$ cm long. He writes: "$g = \dfrac{17.3 - 4.6}{0.82} = 15.5$ cm." Explain why Tom's method is not suitable, and what he should do instead. [4 marks]


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**C4** A chemical breaks down. The mass left, $m$ grams, $t$ hours after the start, is recorded for $0 \leq t \leq 15$, and the regression line is $m = 85 - 3.6t$. Lily finds $m = 16.6$ when $t = 19$ and says: "This is positive, so the estimate is reliable." Explain why Lily is wrong. Then find $m$ when $t = 25$ and comment. [5 marks]


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**C5** Ash records the hours of typing practice in a week, $x$, and her typing speed, $y$ words per minute, for $8$ weeks. Use your calculator to find the regression line of $y$ on $x$. Interpret the gradient, and estimate her speed in a week with $10$ hours of practice. [5 marks]

| $x$ (hours) | 3 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
|---|---|---|---|---|---|---|---|---|
| $y$ (wpm) | 41 | 48 | 50 | 57 | 61 | 66 | 70 | 75 |

Answer .....


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**C6** A shop records the daily rainfall, $w$ mm, and the number of umbrellas sold, $s$, and finds the regression line $s = 42 + 8.5w$, for $0 \leq w \leq 12$. Ben writes: "For each extra umbrella sold, the rainfall increases by $8.5$ mm." Explain Ben's mistake, and interpret both $8.5$ and $42$ correctly. [4 marks]

## D Exam-style questions

Edexcel exam style

**D1** Jo uses the large data set. For $30$ days at Leuchars in 2015, she finds the regression line of the daily maximum gust, $g$ knots, on the daily mean windspeed, $w$ knots: $g = 6.1 + 1.92w$. The values of $w$ range from $4$ to $22$.

**(a)** Interpret the value $1.92$ in context. [2 marks]


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**(b)** Estimate the daily maximum gust on a day with a mean windspeed of $15$ knots. [2 marks]

Answer .....

**(c)** $1$ knot is $1.852$ km/h. Let $G$ and $W$ be the gust and the mean windspeed in km/h. Find the regression line of $G$ on $W$, giving the values to $3$ significant figures. [3 marks]

Answer .....


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**(d)** On one day the maximum gust was $60$ knots. Jo rearranges the line to estimate the mean windspeed that day. Give two reasons why her estimate is not reliable. [3 marks]

**Total for D1: 10 marks**

**D2**

A car is driven from a full tank. The fuel left, $f$ litres, is recorded at $12$ distances, $d$ km, from $0$ to $600$. The regression line of $f$ on $d$ is $f = 52.4 - 0.068d$. Tim writes:

(1) "The gradient $-0.068$ is close to $0$, so the correlation is weak."

(2) "After $50$ km, the fuel has gone down by $52.4 - 0.068 \times 50 = 49$ litres."

(3) "The tank will be empty at $d = \dfrac{52.4}{0.068} = 771$ km."

(4) "The value $52.4$ means the tank holds exactly $52.4$ litres."

Tim has made a mistake in each statement.

**(a)** Explain what is wrong with statement (1). [2 marks]


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**(b)** Correct statement (2). [2 marks]

Answer .....

**(c)** Give two reasons why statement (3) is not reliable. [3 marks]

**(d)** Explain what is wrong with statement (4). [2 marks]

**Total for D2: 9 marks**


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**D3** On $10$ summer days, a shop records the noon temperature, $x$ °C, and the number of ice lollies sold, $y$. The temperatures range from $11$ to $26$ °C. $\sum x = 182$ and $\sum y = 1037$. The regression line of $y$ on $x$ has gradient $4.5$ and passes through the point $(\bar{x}, \bar{y})$. Find the equation of the regression line, interpret the gradient, and estimate the number of lollies sold on a day when the noon temperature is $20$ °C, saying whether your estimate is reliable. Explain whether the value of $a$ has a sensible meaning here. [8 marks]


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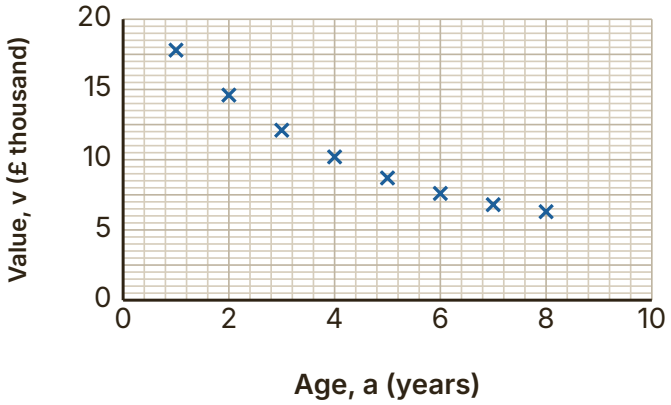
**D4** The scatter diagram shows the age, $a$ years, and the value, $v$ (£ thousand), of $8$ cars of the same model. For ages $1$ to $8$ the values are $17.8$, $14.6$, $12.1$, $10.2$, $8.7$, $7.6$, $6.8$ and $6.3$. The regression line of $v$ on $a$ is $v = 17.7 - 1.60a$.




**(a)** Interpret the value $-1.60$ in context. [2 marks]

**(b)** Use the line to estimate the value of a $4$-year-old car, and compare it with the value in the data. [2 marks]

Answer .....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**(c)** Use the line to estimate the value of a $12$-year-old car, and comment on your answer. [3 marks]

**(d)** With reference to the scatter diagram, explain why a linear model is not the best model for these data. [3 marks]

**Total for D4: 10 marks**


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**D5** A shop sells bars of chocolate of different masses. For $8$ bars, the mass, $x$ grams, and the price, $y$ pence, are shown in the table. The regression line of $y$ on $x$ is $y = 11.8 + 0.958x$.

| $x$ (g) | 25 | 30 | 40 | 45 | 50 | 65 | 70 | 75 |
|---|---|---|---|---|---|---|---|---|
| $y$ (p) | 35 | 41 | 50 | 56 | 60 | 73 | 79 | 84 |

**(a)** Interpret the value $0.958$ in context. [2 marks]

**(b)** Estimate the price of a $55$ g bar. [2 marks]

Answer .....


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**(c)** Another shop sells a $60$ g bar for $90$ p. Use the line to decide whether this is a fair price. [3 marks]

**(d)** Explain why the line should not be used to estimate the price of a $500$ g bar. [2 marks]

**Total for D5: 9 marks**


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**D6** Sara measures the height, $h$ cm, and the arm span, $s$ cm, of $7$ students.

| $h$ (cm) | 152 | 158 | 161 | 165 | 170 | 174 | 180 |
|---|---|---|---|---|---|---|---|
| $s$ (cm) | 150 | 157 | 163 | 166 | 171 | 176 | 183 |

**(a)** Sara wants to estimate arm span from height. Use your calculator to find the regression line she should use. [3 marks]

Answer .....

**(b)** Estimate the arm span of a student who is $165$ cm tall. [2 marks]

Answer .....


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**(c)** Sara says that a person's arm span is equal to their height. [3 marks]
Use your line to estimate the arm spans of students of heights $155$ cm and $175$ cm, and hence comment on her claim.

Answer .....

**Total for D6: 8 marks**


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No route is given. The hints are at the end of the sheet. Use one at a time.

**E1** Data on two variables, $x$ and $y$, are coded with $u = \dfrac{x - 50}{10}$ and $v = \dfrac{y - 200}{5}$. The regression line of $v$ on $u$ is $v = 1.2 + 0.4u$.

**(a)** Find the regression line of $y$ on $x$ in the form $y = a + bx$. [5 marks]

Answer .....

**(b)** Estimate $y$ when $x = 72$, and the change in $y$ when $x$ increases by $15$. [2 marks]

Answer .....



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**(c)** The mean of $x$ is $63$. Find the mean of $y$. [2 marks]

Answer .....

**Total for E1: 9 marks**

## Extension hints

Cover these with paper. Uncover one at a time.

**E1**

**Hint 1** Replace $u$ and $v$ in the coded line by their expressions in $x$ and $y$.

**Hint 2** Multiply both sides by $5$ and add $200$ to make $y$ the subject.

**Hint 3** A regression line passes through the point of means, and coding changes the means in the same way as each value.

## How did it go?

Colour one circle on each line: not yet, nearly, yes.

| | |
|---|---|
| I can interpret the gradient and the intercept of a regression line in context, with units. | ○ ○ ○ |
| I can work out the change in y for a change in x, and estimate y from x. | ○ ○ ○ |
| I can say whether an estimate is interpolation or extrapolation, and whether it is reliable. | ○ ○ ○ |
| I can explain why the line of y on x should not be used to estimate x. | ○ ○ ○ |



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