$$2\mathbf{X}^{\mathrm{T}}\mathbf{X}\boldsymbol{\beta} = 2\underbrace{\begin{pmatrix} 1 & 1 & \dots & 1 \\ x_1 & x_2 & \dots & x_n \end{pmatrix}}_{2\times n}\underbrace{\begin{pmatrix} 1 & x_1 \\ 1 & x_2 \\ \vdots & \vdots \\ 1 & x_n \end{pmatrix}}_{n\times 2}\begin{pmatrix} \beta_0 \\ \beta_1 \end{pmatrix}$$

$$= 2\begin{pmatrix} n & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 \end{pmatrix}\begin{pmatrix} \beta_0 \\ \beta_1 \end{pmatrix}$$

$$= \begin{pmatrix} 2n & 2\sum_{i=1}^{n} x_i \\ 2\sum_{i=1}^{n} x_i & 2\sum_{i=1}^{n} x_i^2 \end{pmatrix}\begin{pmatrix} \beta_0 \\ \beta_1 \end{pmatrix}$$

$$= \begin{pmatrix} 2n\beta_0 + 2\beta_1\sum_{i=1}^{n} x_i \\ 2\beta_0\sum_{i=1}^{n} x_i + 2\beta_1\sum_{i=1}^{n} x_i^2 \end{pmatrix}$$

Note that for any two matrices **A** and **B**, $(\mathbf{AB})^{\mathrm{T}} = \mathbf{B}^{\mathrm{T}}\mathbf{A}^{\mathrm{T}}$. Hence, $\boldsymbol{\beta}^{\mathrm{T}}\mathbf{X}^{\mathrm{T}}\mathbf{X}\boldsymbol{\beta} = (\mathbf{X}\boldsymbol{\beta})^{\mathrm{T}}(\mathbf{X}\boldsymbol{\beta})$.

$$\mathbf{X}\boldsymbol{\beta} = \underbrace{\begin{pmatrix} 1 & x_1 \\ 1 & x_2 \\ \vdots & \vdots \\ 1 & x_n \end{pmatrix}}_{n\times 2}\begin{pmatrix} \beta_0 \\ \beta_1 \end{pmatrix}$$

$$= \begin{pmatrix} \beta_0 + x_1\beta_1 \\ \beta_0 + x_2\beta_1 \\ \vdots \\ \beta_0 + x_n\beta_1 \end{pmatrix}$$

$$(\mathbf{X}\boldsymbol{\beta})^{\mathrm{T}}(\mathbf{X}\boldsymbol{\beta}) = \underbrace{\begin{pmatrix} \beta_0 + x_1\beta_1 & \beta_0 + x_2\beta_1 & \dots & \beta_0 + x_n\beta_1 \end{pmatrix}}_{1\times n}\underbrace{\begin{pmatrix} \beta_0 + x_1\beta_1 \\ \beta_0 + x_2\beta_1 \\ \vdots \\ \beta_0 + x_n\beta_1 \end{pmatrix}}_{n\times 1}$$

$$= \left((\beta_0 + x_1\beta_1)^2 + (\beta_0 + x_2\beta_1)^2 + \dots + (\beta_0 + x_n\beta_1)^2 \right)$$

$$= \left(\sum_{i=1}^{n} (\beta_0 + x_i\beta_1)^2 \right)$$