Q3.2

$$\begin{aligned}
Var(\theta) &= E\left[(\theta - E[\theta])(\theta - E[\theta])^T\right] \\
&= E\left[\left((X^TX)^{-1}X^TY - E[(X^TX)^{-1}X^TY]\right)\cdot\left((X^TX)^{-1}X^TY - E[(X^TX)^{-1}X^TY]\right)^T\right] \\
&= (X^TX)^{-1}X^T \cdot E\left[(Y - E[Y])\cdot(Y - E[Y])^T\right] \cdot ((X^TX)^{-1}X^T)^T
\end{aligned}$$

Because $Y - E[Y] = X\theta + \varepsilon - E[X\theta + \varepsilon] = \varepsilon$

$$\begin{aligned}
&= (X^TX)^{-1}X^T \cdot E[\varepsilon\cdot\varepsilon^T]\cdot\left((X^TX)^{-1}X^T\right)^T \\
&= (X^TX)^{-1}X^T \cdot \sigma^2 \cdot \left((X^TX)^{-1}X^T\right)^T \\
&= (X^TX)^{-1}X^T \cdot X\left((X^TX)^{-1}\right)^T \cdot \sigma^2 \\
&= (X^TX)^{-1}(X^T \cdot X)\cdot(X^TX)^{-1}\cdot\sigma^2 \\
&= (X^TX)^{-1}\cdot\sigma^2
\end{aligned}$$