Random Variables (rvs)

Expectation of sums of random variables [Ross S4.9]

Recall, a random variable X is a function $X(s)$ of the outcome s of a random experiment.

We can have two functions of the same outcome s, say $X(s)$ and $Y(s)$.

Example 14.1: Flip a coin 5 times.

Let $X = \#$ heads in first 3 flips; $Y = \#$ heads in last 2 flips.

Since X and Y are numbers, we can add them: $Z(s) = X(s) + Y(s)$.

In other words, Z is also a random variable.

Here, $Z = \#$ of heads in all 5 flips.

Now, for each $s \in S$, let $p(s) = P[\{s\}]$.

Then $P[A] = \sum_{s \in A} p(s)$

Let
$$X \in \mathcal{X} = \{x_1, \ldots, x_n\}$$
$$A_k = \{s \in S \mid X(s) = x_k\}$$

Then
$$\begin{aligned} E[X] &= \sum_{k=1}^{n} x_k P[X = x_k] \\ &= \sum_{k=1}^{n} x_k P[A_k] \\ &= \sum_{k=1}^{n} x_k \sum_{s \in A_k} p(s) \\ &= \sum_{k=1}^{n} \sum_{s \in A_k} x_k p(s) \\ &= \sum_{k=1}^{n} \sum_{s \in A_k} X(s) p(s) \\ &= \sum_{s \in S} X(s) p(s) \end{aligned}$$

Example 14.2: Two independent flips of a fair coin are made.

Let $X = \#$ heads.

Then
$$\begin{aligned} P[X = 0] &= 1/4 \\ P[X = 1] &= 1/2 \\ P[X = 2] &= 1/4 \end{aligned}$$

So $\quad E[X] = 0 \times \frac{1}{4} + 1 \times \frac{1}{2} + 2 \times \frac{1}{4} = 1.$

Also, $S = \{tt, th, ht, hh\}$, and each outcome has probability 1/4.

So
$$\begin{aligned} E[X] &= X(tt) \times \frac{1}{4} + X(th) \times \frac{1}{4} + X(ht) \times \frac{1}{4} + X(hh) \times \frac{1}{4} \\ &= 0 \times \frac{1}{4} \qquad + 1 \times \frac{1}{4} \qquad + 1 \times \frac{1}{4} \qquad + 2 \times \frac{1}{4} \\ &= 1 \end{aligned}$$

Proposition 14.1 *For random variables $X_1, X_2, \ldots, X_n$:*

$$E[X_1 + \cdots + X_n] = E[X_1] + \cdots + E[X_n]$$

Why?

Let $Z = X_1 + \cdots + X_n$. Then

$$\begin{aligned} E[Z] &= \sum_{s \in S} Z(s) p(s) \\ &= \sum_{s \in S} (\, X_1(s) + \cdots + X_n(s)\,) p(s) \\ &= \sum_{s \in S} X_1(s) p(s) + \cdots + \sum_{s \in S} X_n(s) p(s) \\ &= E[X_1] + \cdots + E[X_n] \end{aligned}$$

Example 14.3: Let $X \sim \mathsf{Binomial}(n, p)$. Then

$$X = X_1 + \cdots + X_n$$

where each $X_k \sim \mathsf{Bernoulli}(p)$ and is an independent trial.

Then:

$$\begin{aligned} E[X] &= E[X_1 + \cdots + X_n] \\ &= E[X_1] + \cdots + E[X_n] \\ &= p + \cdots + p \\ &= np \end{aligned}$$

$$\begin{aligned} E[X^2] &= E\left[\left(\sum_{k=1}^{n} X_k \right) \left(\sum_{\ell=1}^{n} X_\ell \right) \right] \\ &= E\left[\sum_{k=1}^{n} \left(\sum_{\ell=1}^{n} X_k X_\ell \right) \right] \\ &= E\left[\sum_{k=1}^{n} \left(X_k X_k + \sum_{\substack{\ell=1 \\ \ell \neq k}}^{n} X_k X_\ell \right) \right] \\ &= E\left[\sum_{k=1}^{n} X_k^2 + \sum_{k=1}^{n} \sum_{\substack{\ell=1 \\ \ell \neq k}}^{n} X_k X_\ell \right] \\ &= \sum_{k=1}^{n} E\left[X_k^2\right] + \sum_{k=1}^{n} \sum_{\substack{\ell=1 \\ \ell \neq k}}^{n} E\left[X_k X_\ell\right] \end{aligned}$$

Now
$$\begin{aligned} P[X_k^2 = 1] &= P[X_k = 1] = p \\ P[X_k X_\ell = 1] &= P[X_k = 1, X_\ell = 1] \\ &= P[X_k = 1] P[X_\ell = 1] \quad \text{[since trials are independent]} \\ &= p^2 \end{aligned}$$

So $\quad E[X^2] = np + n(n-1)p^2$

Properties of CDFs [Ross 4.10]

Recall $F_X(x) = P[X \le x]$

Therefore:

1) $0 \le F_X(x) \le 1$
2) If $a < b$ then $\{X \le a\} \subset \{X \le b\}$
   $\Rightarrow P[X \le a] \le P[X \le b]$
   $\Rightarrow F_X(a) \le F_X(b)$

   or, $F_X(x)$ is non-decreasing in x.

It can also be show that:

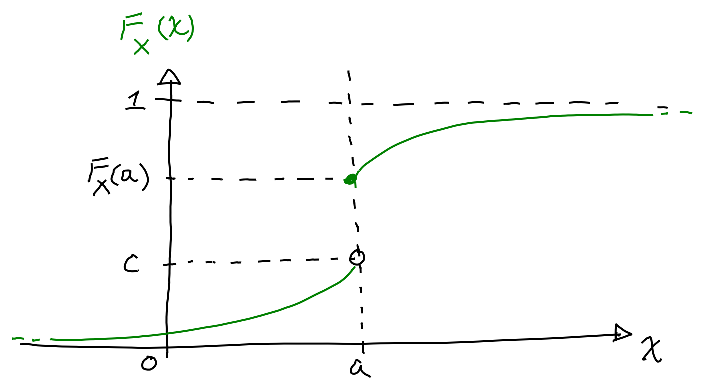
3) $\lim_{x \to \infty} F_X(x) = 1$
4) $\lim_{x \to -\infty} F_X(x) = 0$
5) $\lim_{x \downarrow b} F_X(x) = F_X(b)$

   [i.e., $F_X(x)$ is continuous from the right]
6) $\lim_{x \uparrow b} F_X(x)$ exists

   [i.e., $F_X(x)$ has left limits]

A function with properties 5) and 6) is called **càdlàg** [continue à droite, limite à gauche].

Example 14.4:



Here:

$$\lim_{x \downarrow a} F_X(x) = F_X(a)$$

$$\lim_{x \uparrow a} F_X(x) = c \neq F_X(a)$$