

# Economics 103 – Statistics for Economists

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Lecture # 12

## Continuous RVs II: The Normal RV



Figure: Standard Normal RV (PDF)

## Standard Normal Random Variable: $N(0, 1)$

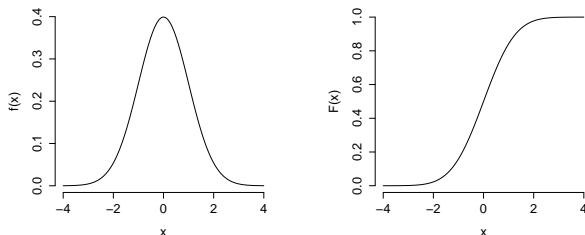
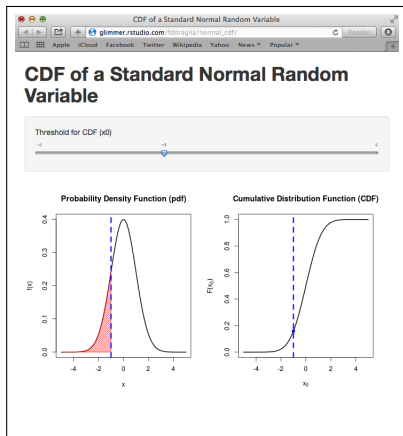


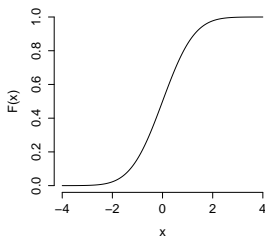
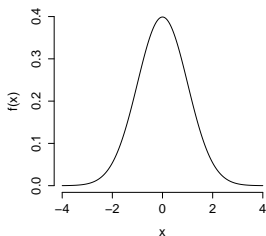
Figure: Standard Normal PDF (left) and CDF (Right)

- ▶ Notation:  $X \sim N(0, 1)$
- ▶ Symmetric, Bell-shaped,  $E[X] = 0$ ,  $Var[X] = 1$
- ▶ Support Set =  $(-\infty, \infty)$

[http://glimmer.rstudio.com/fditraglia/normal\\_cdf/](http://glimmer.rstudio.com/fditraglia/normal_cdf/)



## Standard Normal Random Variable: $N(0, 1)$



- ▶ There is no closed-form expression for the  $N(0, 1)$  CDF.
- ▶ For Econ 103, don't need to know formula for  $N(0, 1)$  PDF.
- ▶ You *do need* to know the R commands. . .

# R Commands for the Standard Normal RV

## `dnorm` – Standard Normal PDF

- ▶ Mnemonic: `d` = density, `norm` = normal
- ▶ Example: `dnorm(0)` gives height of  $N(0, 1)$  PDF at zero.

## `pnorm` – Standard Normal CDF

- ▶ Mnemonic: `p` = probability, `norm` = normal
- ▶ Example: `pnorm(1)` =  $P(X \leq 1)$  if  $X \sim N(0, 1)$ .

## `rnorm` – Simulate Standard Normal Draws

- ▶ Mnemonic: `r` = random, `norm` = normal.
- ▶ Example: `rnorm(10)` makes ten iid  $N(0, 1)$  draws.

$\Phi(x_0)$  Denotes the  $N(0, 1)$  CDF

You will sometimes encounter the notation  $\Phi(x_0)$ . It means the same thing as `pnorm(x0)` but it's not an R command.

# The $N(\mu, \sigma^2)$ Random Variable

## Idea

Take a linear function of the  $N(0, 1)$  RV.

## Formal Definition

$N(\mu, \sigma^2) \equiv \mu + \sigma X$  where  $X \sim N(0, 1)$  and  $\mu, \sigma$  are constants.

## Properties of $N(\mu, \sigma^2)$ RV

- ▶ Parameters: Expected Value =  $\mu$ , Variance =  $\sigma^2$
- ▶ Symmetric and bell-shaped.
- ▶ Support Set =  $(-\infty, \infty)$
- ▶  $N(0, 1)$  is the special case where  $\mu = 0$  and  $\sigma^2 = 1$ .



## Expected Value: $\mu$ shifts PDF

all of these have  $\sigma = 1$

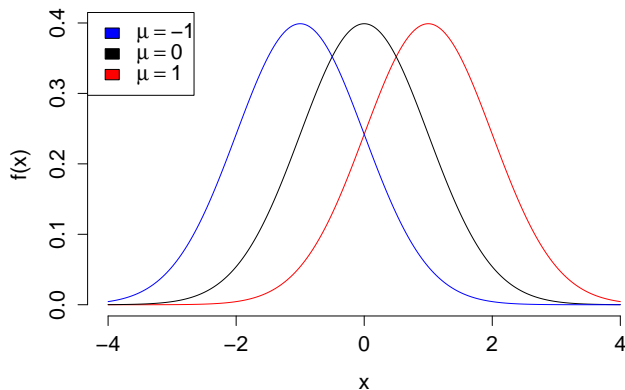


Figure: Blue  $\mu = -1$ , Black  $\mu = 0$ , Red  $\mu = 1$

# Standard Deviation: $\sigma$ scales PDF

all of these have  $\mu = 0$

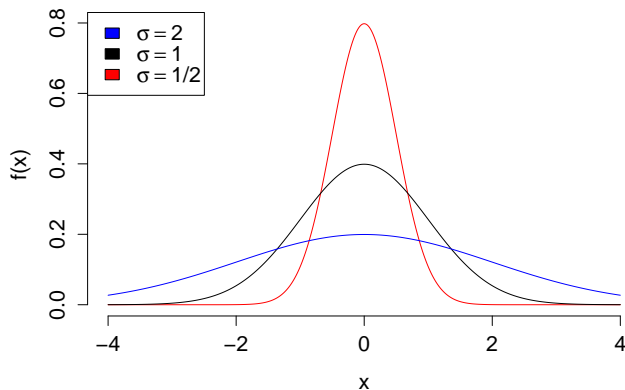


Figure: Blue  $\sigma^2 = 4$ , Black  $\sigma^2 = 1$ , Red  $\sigma^2 = 1/4$

# Linear Function of Normal RV is a Normal RV

Suppose that  $X \sim N(\mu, \sigma^2)$ . Then if  $a$  and  $b$  constants,

$$a + bX \sim N(a + b\mu, b^2\sigma^2)$$

## Important

- ▶ For *any* RV  $X$ ,  $E[a + bX] = a + bE[X]$  and  $Var(a + bX) = b^2 Var(X)$ .
- ▶ Key point: linear transformation of normal is still normal!
- ▶ Linear transformation of Binomial is *not* Binomial!

## Example



Suppose  $X \sim N(\mu, \sigma^2)$  and let  $Z = (X - \mu)/\sigma$ . What is the distribution of  $Z$ ?

- (a)  $N(\mu, \sigma^2)$
- (b)  $N(\mu, \sigma)$
- (c)  $N(0, \sigma^2)$
- (d)  $N(0, \sigma)$
- (e)  $N(0, 1)$

## Linear Combinations of *Multiple Independent* Normals

Let  $X \sim N(\mu_x, \sigma_x^2)$  independent of  $Y \sim N(\mu_y, \sigma_y^2)$ . Then if  $a, b, c$  are constants:

$$aX + bY + c \sim N(a\mu_x + b\mu_y + c, a^2\sigma_x^2 + b^2\sigma_y^2)$$

### Important

- ▶ Result assumes independence
- ▶ Particular to Normal RV
- ▶ Extends to more than two Normal RVs

Suppose  $X_1, X_2, \sim \text{iid } N(\mu, \sigma^2)$



Let  $\bar{X} = (X_1 + X_2)/2$ . What is the distribution of  $\bar{X}$ ?

- (a)  $N(\mu, \sigma^2/2)$
- (b)  $N(0, 1)$
- (c)  $N(\mu, \sigma^2)$
- (d)  $N(\mu, 2\sigma^2)$
- (e)  $N(2\mu, 2\sigma^2)$

# Where does the Empirical Rule come from?

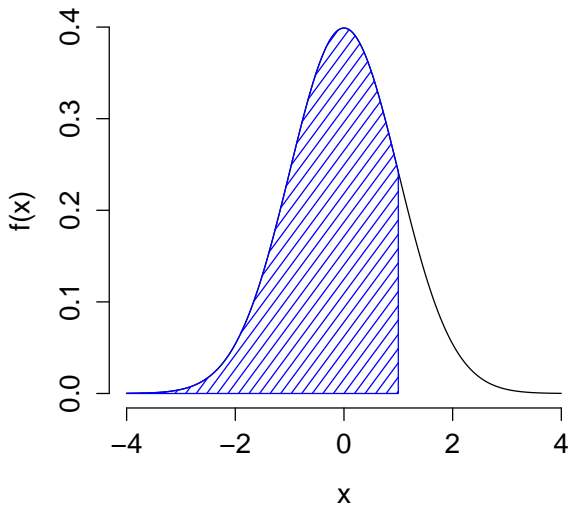
## Empirical Rule

Approximately 68% of observations within  $\mu \pm \sigma$

Approximately 95% of observations within  $\mu \pm 2\sigma$

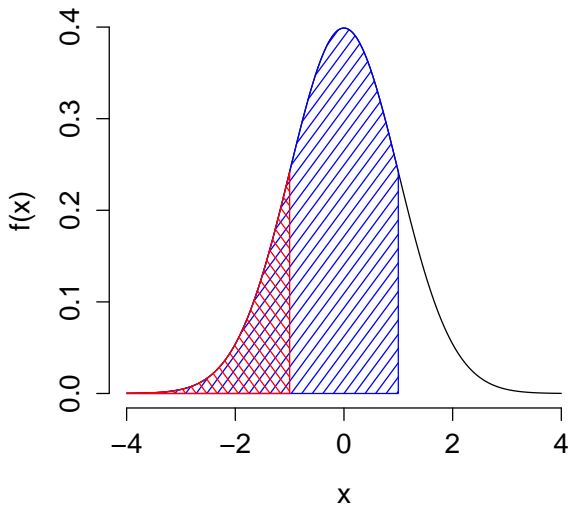
Nearly all observations within  $\mu \pm 3\sigma$

$$\text{pnorm}(1) \approx 0.84$$

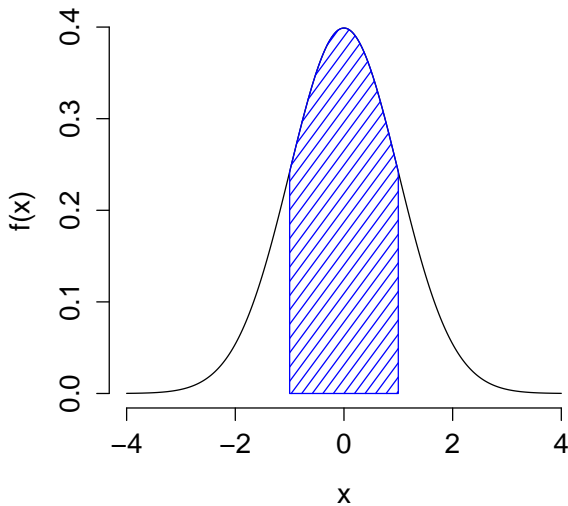




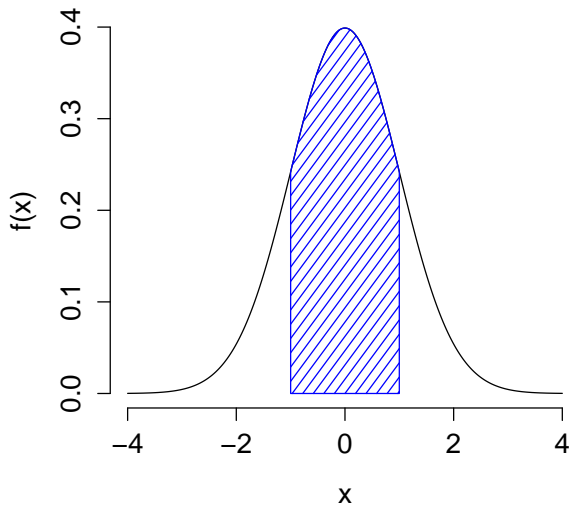
$$\text{pnorm}(1) - \text{pnorm}(-1) \approx 0.84 - 0.16$$



$$\text{pnorm}(1) - \text{pnorm}(-1) \approx 0.68$$



Middle 68% of  $N(0, 1) \Rightarrow$  approx.  $(-1, 1)$



Suppose  $X \sim N(0, 1)$

$$\begin{aligned} P(-1 \leq X \leq 1) &= \text{pnorm}(1) - \text{pnorm}(-1) \\ &\approx 0.683 \end{aligned}$$

$$\begin{aligned} P(-2 \leq X \leq 2) &= \text{pnorm}(2) - \text{pnorm}(-2) \\ &\approx 0.954 \end{aligned}$$

$$\begin{aligned} P(-3 \leq X \leq 3) &= \text{pnorm}(3) - \text{pnorm}(-3) \\ &\approx 0.997 \end{aligned}$$

What if  $X \sim N(\mu, \sigma^2)$ ?

$$\begin{aligned}P(X \leq a) &= P(X - \mu \leq a - \mu) \\&= P\left(\frac{X - \mu}{\sigma} \leq \frac{a - \mu}{\sigma}\right) \\&= P\left(Z \leq \frac{a - \mu}{\sigma}\right)\end{aligned}$$

Where  $Z$  is a standard normal random variable, i.e.  $N(0, 1)$ .



Which of these equals  $P(Z \leq (a - \mu)/\sigma)$  if  $Z \sim N(0, 1)$ ?

- (a) `pnorm(a)`
- (b)  $1 - \text{pnorm}(a)$
- (c)  $\text{pnorm}(a)/\sigma - \mu$
- (d)  $\text{pnorm}\left(\frac{a-\mu}{\sigma}\right)$
- (e) None of the above.

## Probability Above a Threshold: $X \sim N(\mu, \sigma^2)$

$$\begin{aligned}P(X \geq b) &= 1 - P(X \leq b) = 1 - P\left(\frac{X - \mu}{\sigma} \leq \frac{b - \mu}{\sigma}\right) \\&= 1 - P\left(Z \leq \frac{b - \mu}{\sigma}\right) \\&= 1 - \text{pnorm}((b - \mu)/\sigma)\end{aligned}$$

Where  $Z$  is a standard normal random variable.

## Probability of an Interval: $X \sim N(\mu, \sigma^2)$

$$\begin{aligned}P(a \leq X \leq b) &= P\left(\frac{a - \mu}{\sigma} \leq \frac{X - \mu}{\sigma} \leq \frac{b - \mu}{\sigma}\right) \\&= P\left(\frac{a - \mu}{\sigma} \leq Z \leq \frac{b - \mu}{\sigma}\right) \\&= \text{pnorm}((b - \mu)/\sigma) - \text{pnorm}((a - \mu)/\sigma)\end{aligned}$$

Where  $Z$  is a standard normal random variable.



Suppose  $X \sim N(\mu, \sigma^2)$



What is  $P(\mu - \sigma \leq X \leq \mu + \sigma)$ ?

$$\begin{aligned} P(\mu - \sigma \leq X \leq \mu + \sigma) &= P\left(-1 \leq \frac{X - \mu}{\sigma} \leq 1\right) \\ &= P(-1 \leq Z \leq 1) \\ &= \text{pnorm}(1) - \text{pnorm}(-1) \\ &\approx 0.68 \end{aligned}$$

## Percentiles/Quantiles for Continuous RVs

Quantile Function  $Q(p)$  is the inverse of CDF  $F(x_0)$

Plug in a probability  $p$ , get out the value of  $x_0$  such that  $F(x_0) = p$

$$Q(p) = F^{-1}(p)$$

In other words:

$$Q(p) = \text{the value of } x_0 \text{ such that } \int_{-\infty}^{x_0} f(x) dx = p$$

Inverse exists as long as  $F(x_0)$  is *strictly increasing*.

## Example: Median

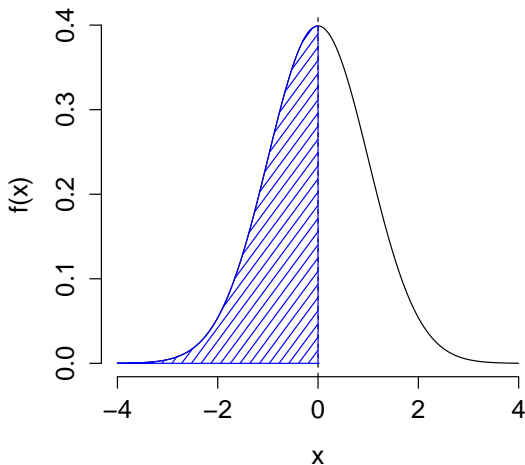
The median of a continuous random variable is  $Q(0.5)$ , i.e. the value of  $x_0$  such that

$$\int_{-\infty}^{x_0} f(x) dx = 1/2$$

## What is the median of a standard normal RV?

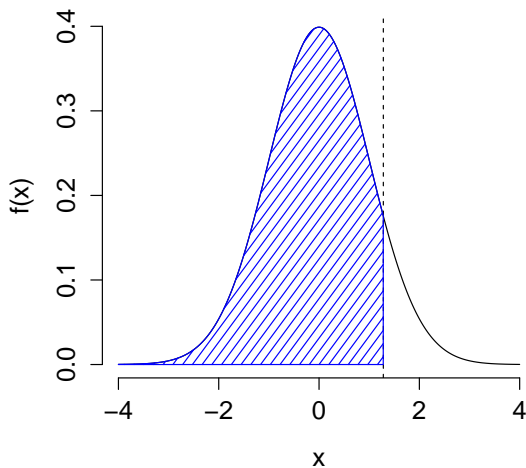


By symmetry,  $Q(0.5) = 0$ . R command: `qnorm()`



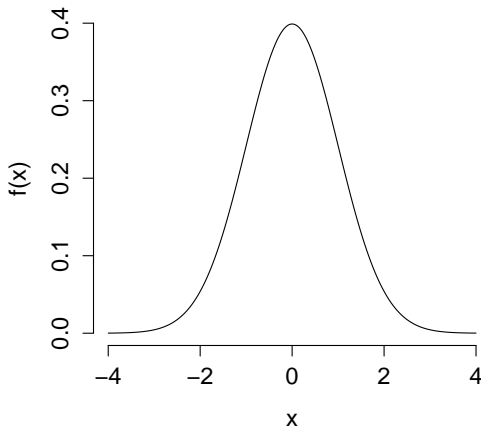
## 90th Percentile of a Standard Normal

$$\text{qnorm}(0.9) \approx 1.28$$



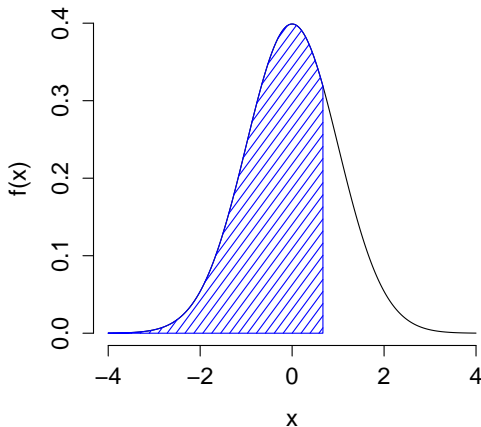
## Using Quantile Function to find Symmetric Intervals

Suppose  $X$  is a standard normal RV. What is the value of  $c$  such that  $P(-c \leq X \leq c) = 0.5$ ?



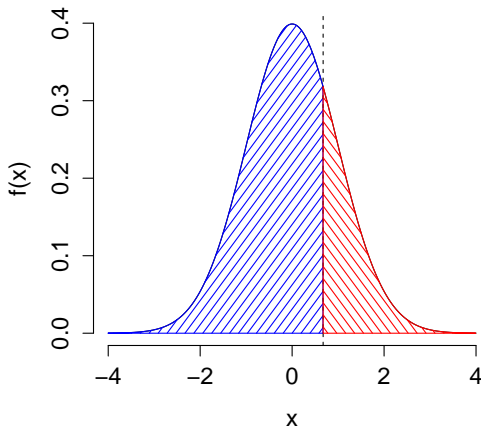
$$\text{qnorm}(0.75) \approx 0.67$$

Suppose  $X$  is a standard normal RV. What is the value of  $c$  such that  $P(-c \leq X \leq c) = 0.5$ ?



$$\text{qnorm}(0.75) \approx 0.67$$

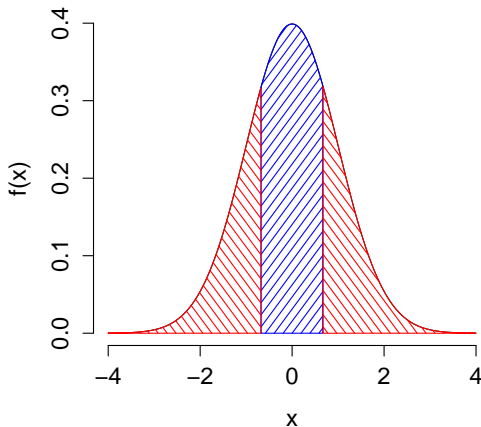
Suppose  $X$  is a standard normal RV. What is the value of  $c$  such that  $P(-c \leq X \leq c) = 0.5$ ?





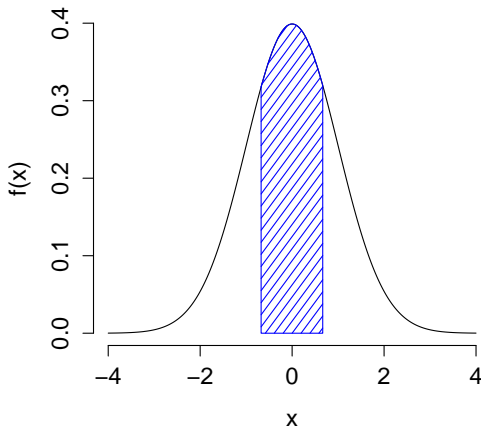
$$\text{pnorm}(0.67) - \text{pnorm}(-0.67) \approx ?$$

Suppose  $X$  is a standard normal RV. What is the value of  $c$  such that  $P(-c \leq X \leq c) = 0.5$ ?



$$\text{pnorm}(0.67) - \text{pnorm}(-0.67) \approx 0.5$$

Suppose  $X$  is a standard normal RV. What is the value of  $c$  such that  $P(-c \leq X \leq c) = 0.5$ ?



## 95% Central Interval for Standard Normal



Suppose  $X$  is a standard normal random variable. What value of  $c$  ensures that  $P(-c \leq X \leq c) \approx 0.95$ ?

## R Commands for *Arbitrary* Normal RVs

Let  $X \sim N(\mu, \sigma^2)$  . Then we can use R to evaluate the CDF and Quantile function of  $X$  as follows:

CDF $F(x)$	<code>pnorm(x, mean = <math>\mu</math>, sd = <math>\sigma</math>)</code>
Quantile Function $Q(p)$	<code>qnorm(p, mean = <math>\mu</math>, sd = <math>\sigma</math>)</code>

Notice that this means you don't have to transform  $X$  to a standard normal in order to find areas under its pdf using R.

## Example from Homework: $X \sim N(0, 16)$

One Way:

$$\begin{aligned}P(X \geq 10) &= 1 - P(X \leq 10) = 1 - P(X/4 \leq 10/4) \\&= 1 - P(Z \leq 2.5) = 1 - \Phi(2.5) = 1 - \text{pnorm}(2.5) \\&\approx 0.006\end{aligned}$$

An Easier Way:

$$\begin{aligned}P(X \geq 10) &= 1 - P(X \leq 10) \\&= 1 - \text{pnorm}(10, \text{mean} = 0, \text{sd} = 4) \\&\approx 0.006\end{aligned}$$