TÉCNICO LISBOA



# Sustainable Development, Economic Growth and Energy

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*with*

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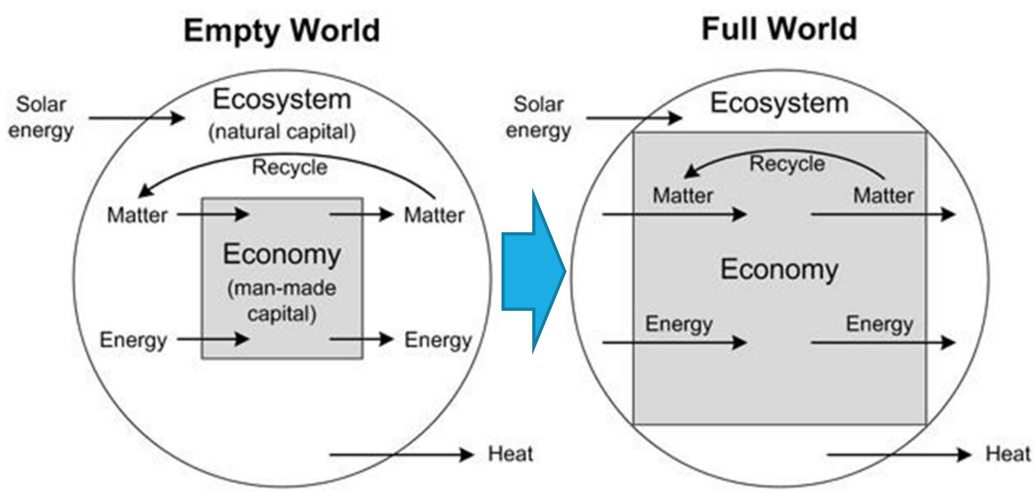
# THE GLOBAL ECOSYSTEM AND THE ECONOMIC SUBSYSTEM




Goodland, Daly, El Serafy (1992)

**Scale**

- Size of the population (P)
- Size of the consumption per capita (A) e technology efficiency (T)

Size of the planet/environment:

- Production of natural resources
- Assimilation of wastes

Impact on the planet (I)

**I = PxAxT**

# Big History: Summary

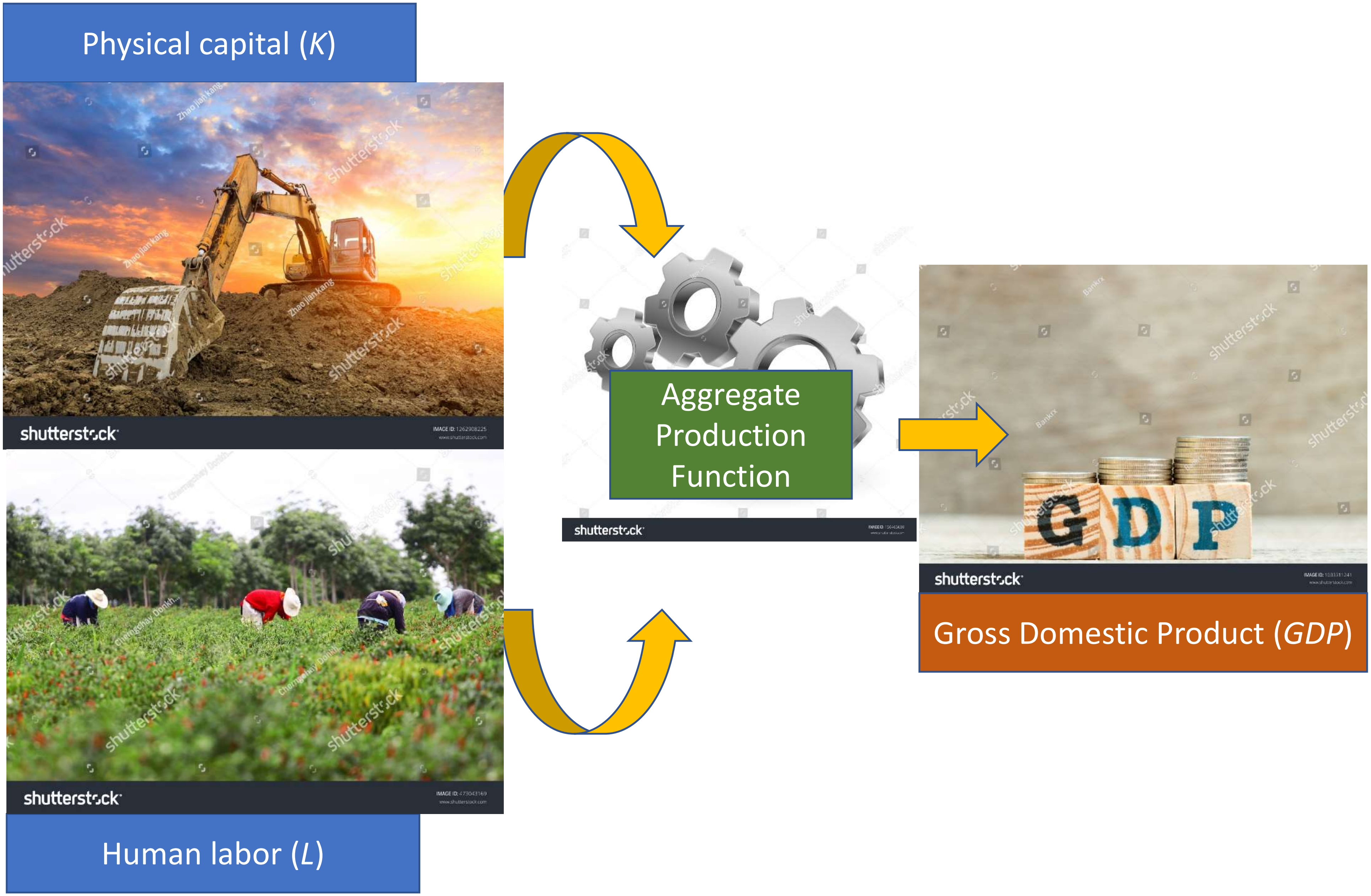
## Summary

| Big bang | Stars | Planets | Life | Humans | Civilization |
|---|---|---|---|---|---|
| Spacetime | Stars | Molecules | Replicator | Primates | Religion |
| Particles | Nucleus (heavy) | Environments | Cell | Homo | Agriculture |
| Nucleons | White dwarfs | (atmosphere, | Prokaryote | Collective learning | Agrovillages |
| Nucleus (light) | Neutron stars | liquid medium, | Photosynthesis | Language | Civilizations |
| Atoms | Blackholes | solid medium) | Eukaryote | Tribes | Writing |
| | Stellar systems | Moon | Multicellulars | Out of Africa | Money |
| | Galaxies | Plate tectonics | Land invasion | Tools | Law |
| | Clusters | | Animals | | Globalization |
| | | | Mammals | | |
| | | | Eusociality | | |

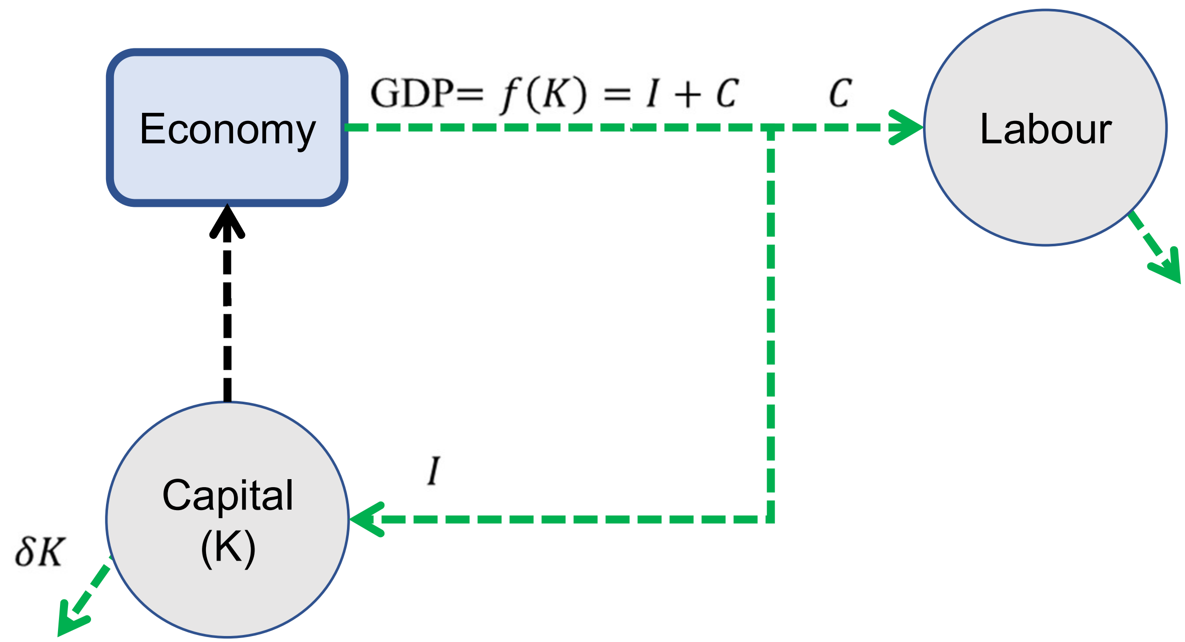
# Industrialisation and Economic Growth

First globalization **1s**

# Economic growth: Factors of production and aggregate production function

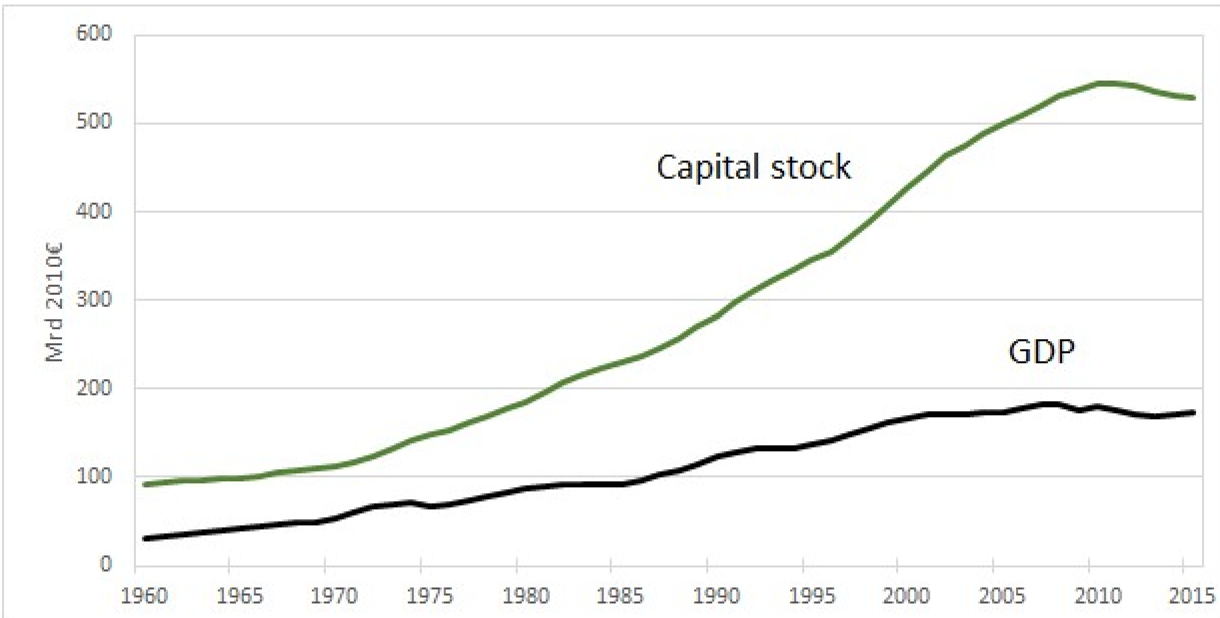


# The Simplest Economic Growth Model: Capital (K) as the Single Factor of Production




$$\frac{dK}{dt} = I - \delta K = f(K) - C - \delta K$$
$$= sf(K) - \delta K$$

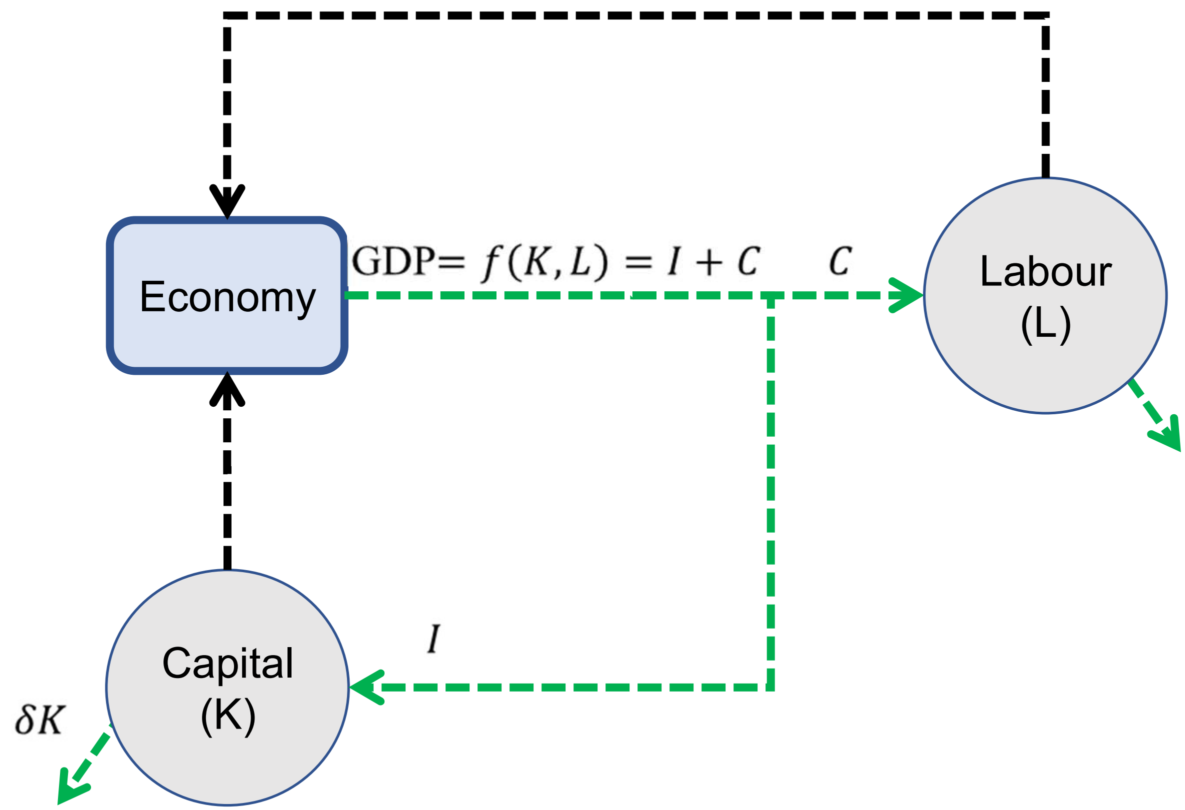
# Economic Growth in Portugal, 1960-2009




$$\text{GDP} = f(K)$$

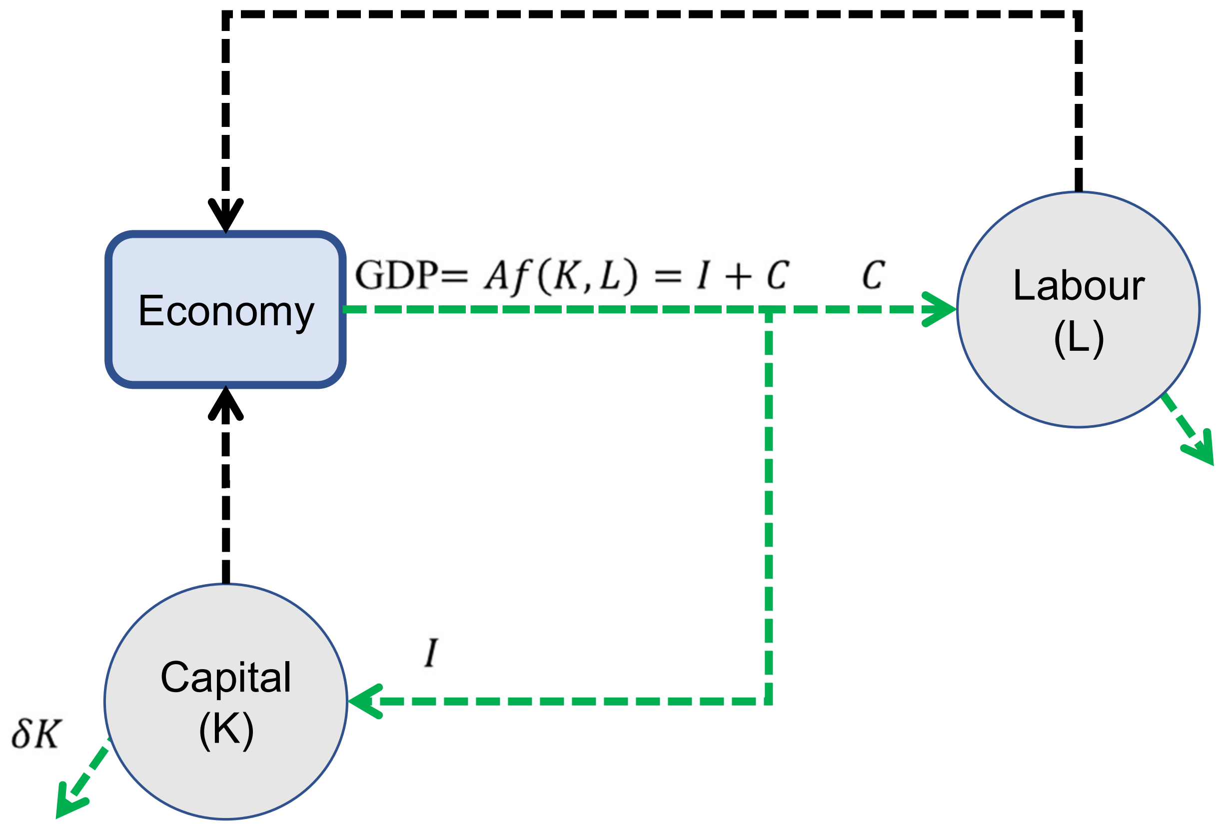
$$\frac{dK}{dt} = sf(K) - \delta K$$

# A Slightly Less Simple Economic Growth Model: Labour (L) as a Production Factor



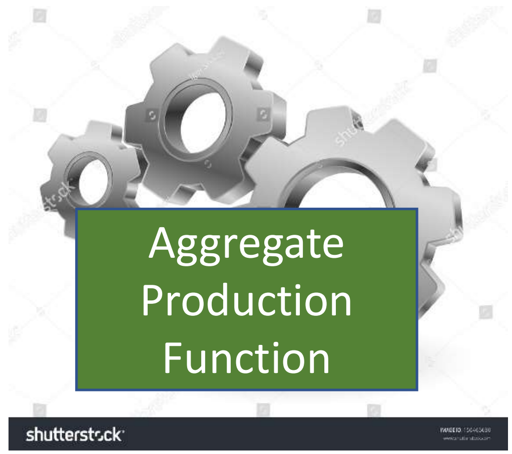

$$\frac{dK}{dt} = I - \delta K = f(K,L) - C - \delta K$$
$$= sf(K,L) - \delta K$$

# An Even Slightly Less Simple Economic Growth Model: Total Factor Productivity (A)




$$\frac{dK}{dt} = I - \delta K = Af(K,L) - C - \delta K$$
$$= sAf(K,L) - \delta K$$

# Factors of production and aggregate production function




Cobb-Douglas (C-D) production function:

**Output elasticity** ($\alpha$)

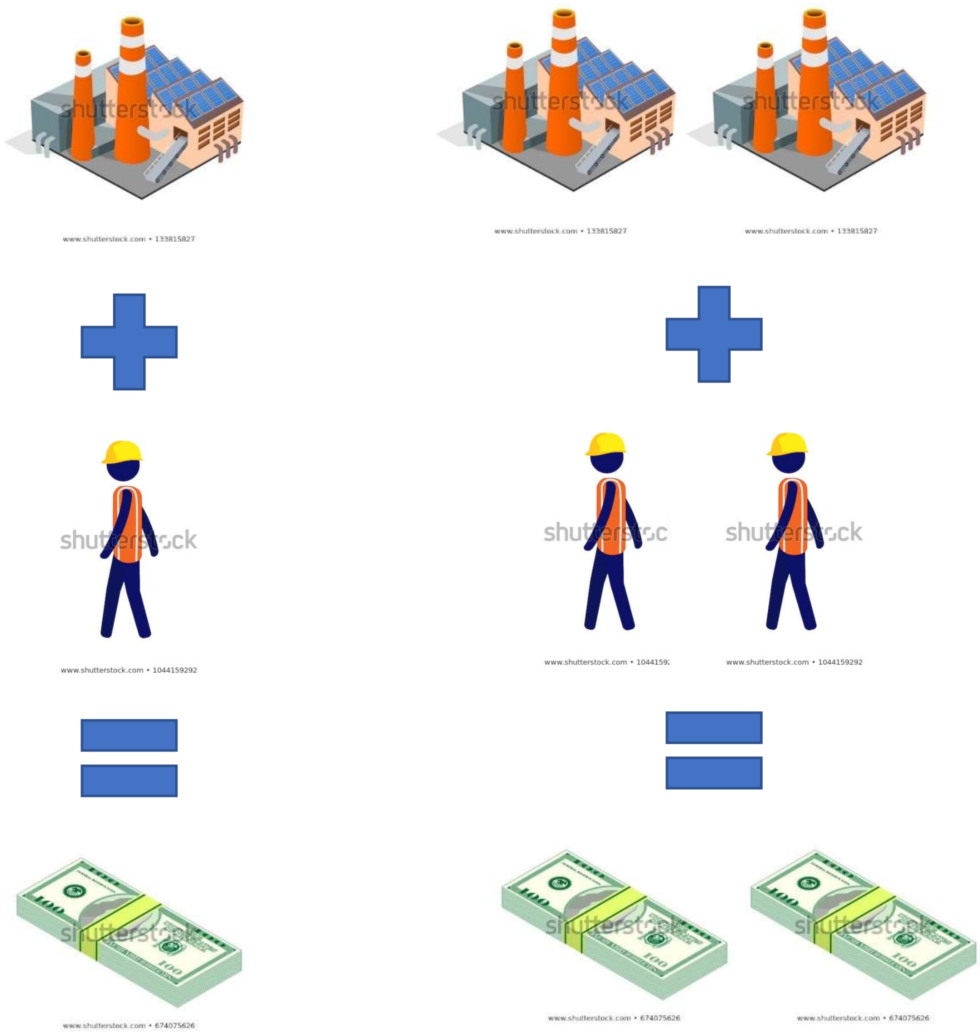
$$GDP = AK^{\alpha}L^{1-\alpha}$$

Gross Domestic Product (*GDP*)

Physical capital (*K*)

Human labor (*L*)

# Constant returns to scale in the production function



$$GDP = AK^{\alpha}L^{1-\alpha}$$

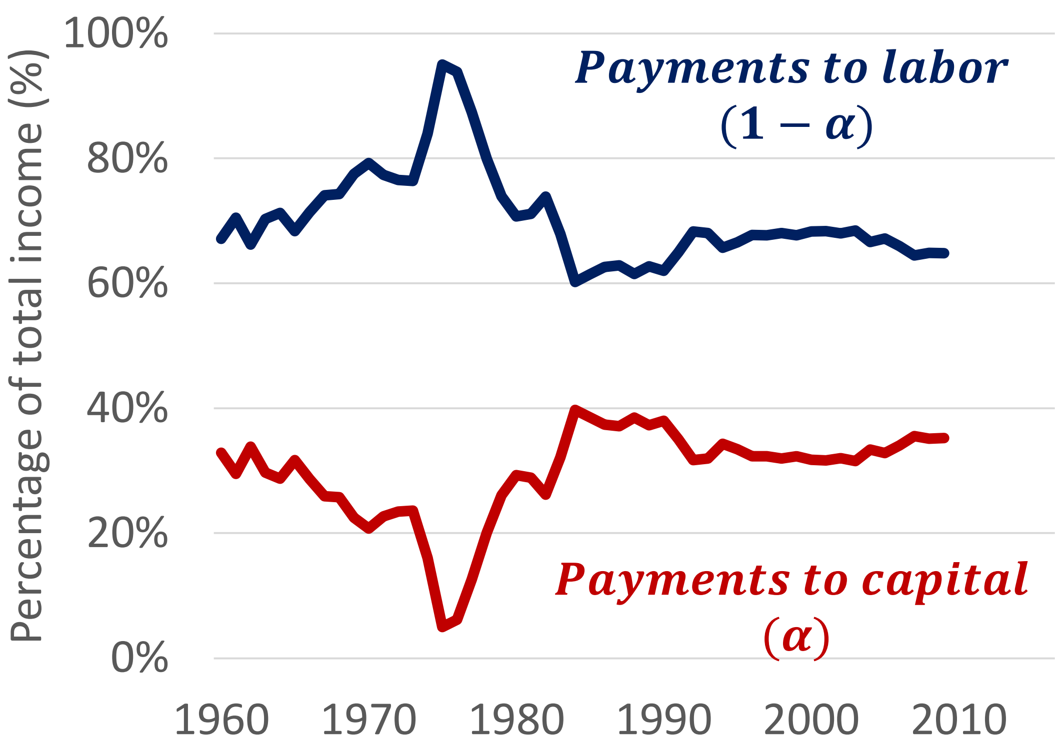
$$= A(2K)^{\alpha}(2L)^{1-\alpha}$$

$$= A(2^{\alpha})K^{\alpha}(2^{1-\alpha})L^{1-\alpha}$$

$$= 2AK^{\alpha}L^{1-\alpha}$$

$$= 2GDP$$

# Factors of production and aggregate production function

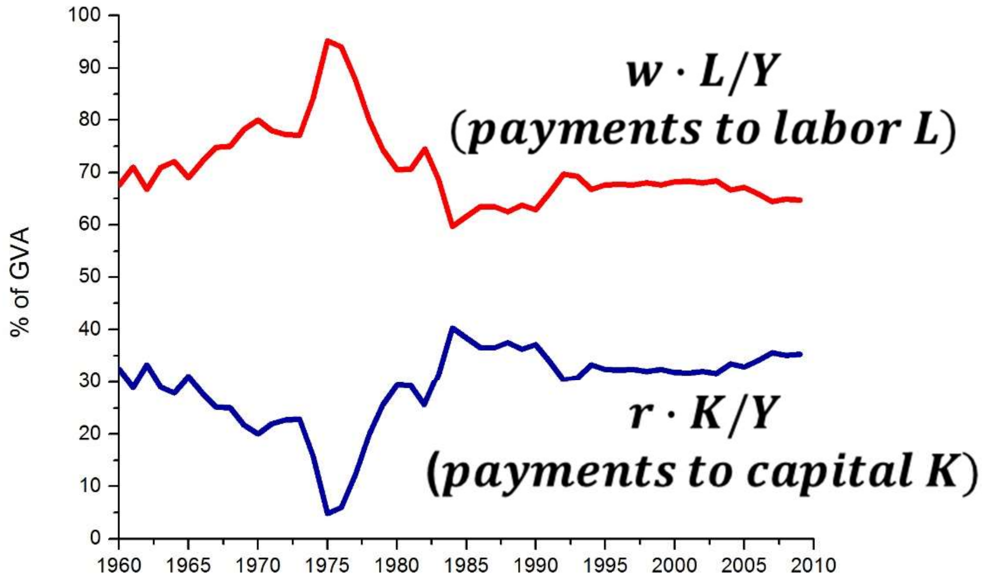


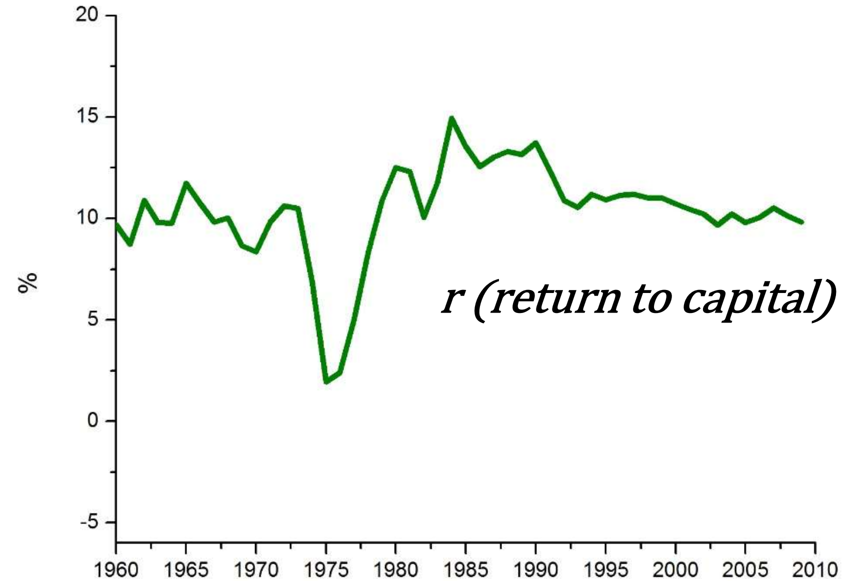


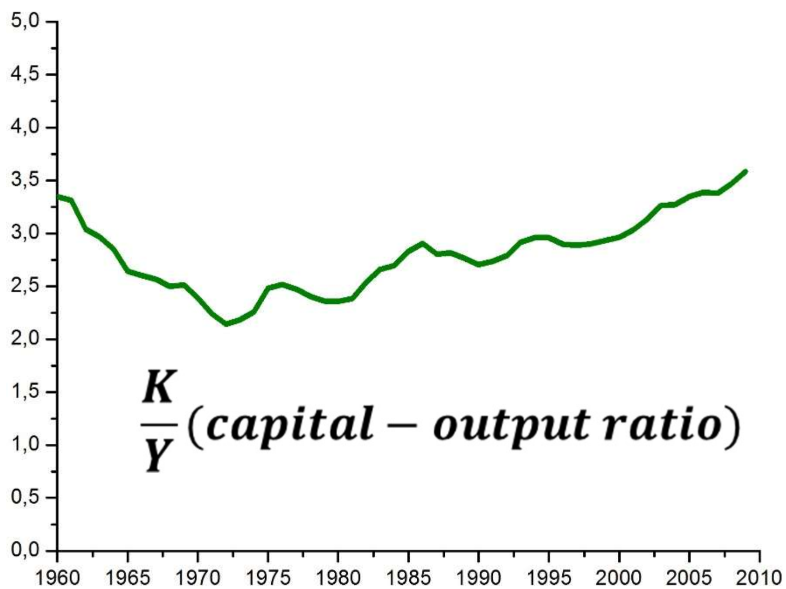

For developed countries (e.g. Portugal), output elasticities average to 30% for capital (rents and interest) and 70% for labor (wages and salaries).

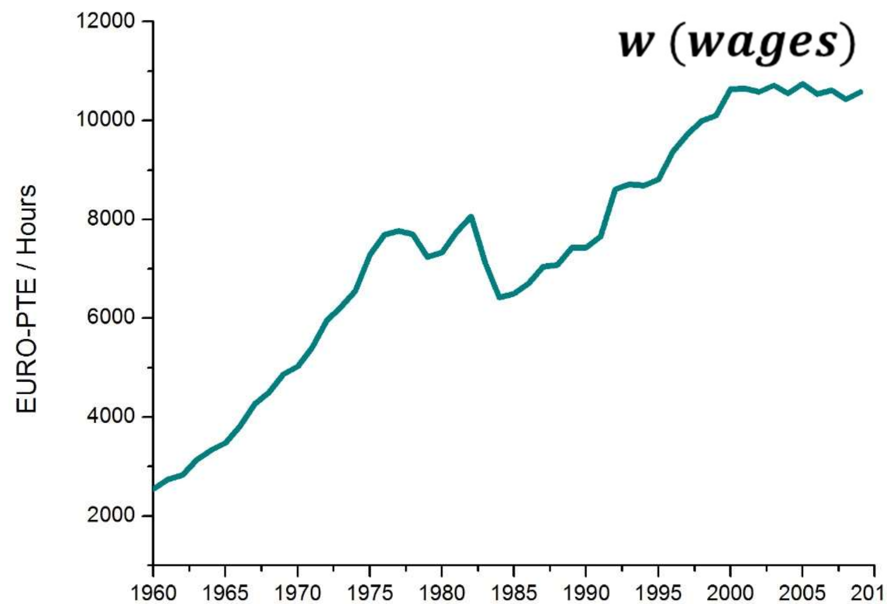
# Kaldor facts – Portugal 1960-2009

$$(Output)Y = r \cdot K + w \cdot L$$



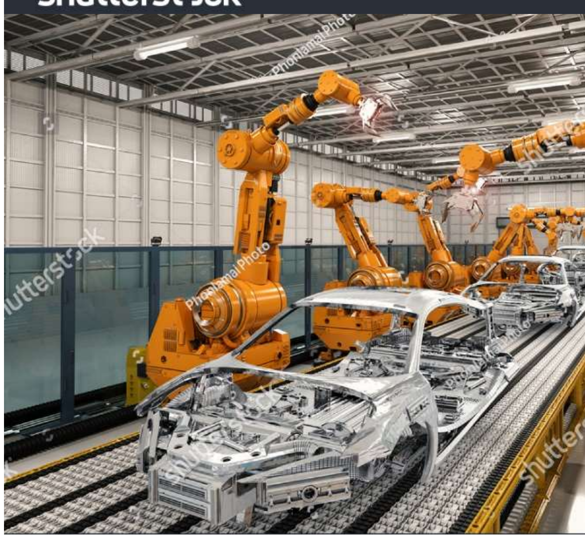



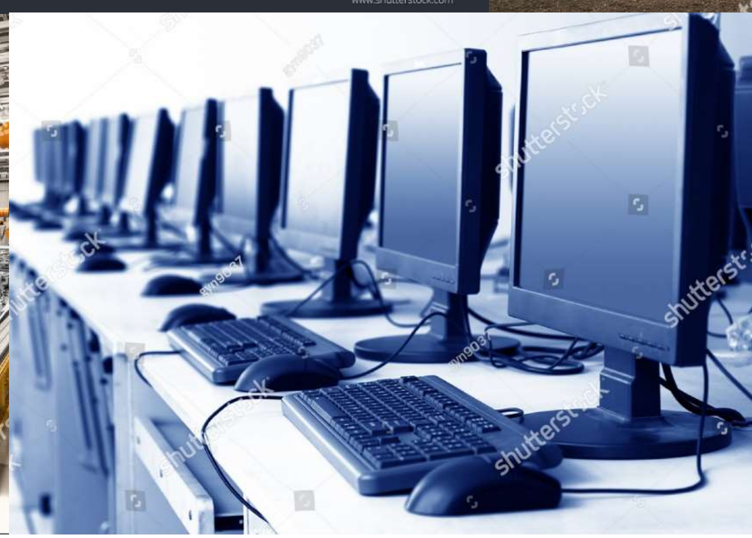



# Factors of production: Physical capital

Total money value of buildings, machines, and tools used in the production of goods and services

-> Capital stock

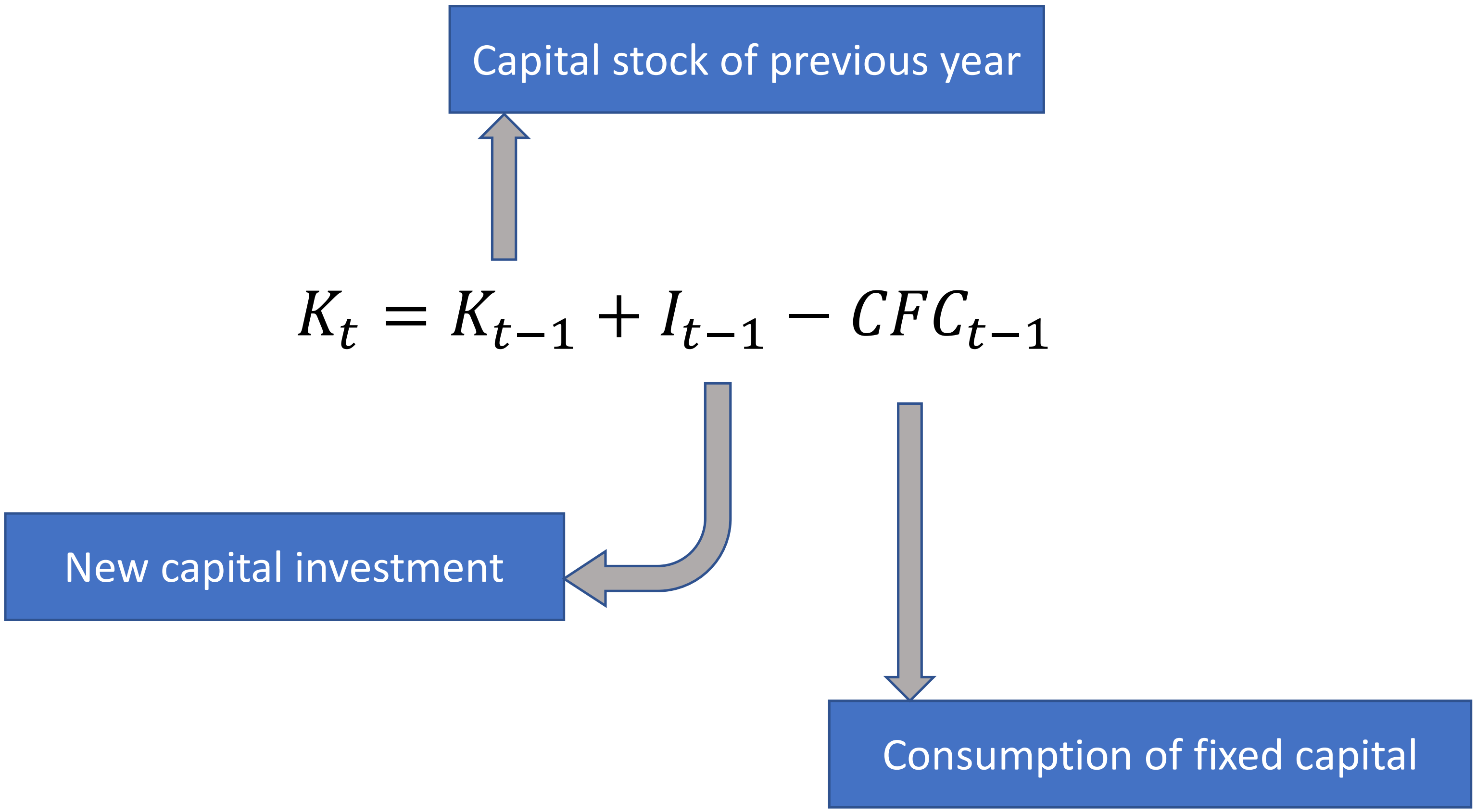




# Factors of production: Physical capital

Capital stock available for production each year depends on:

$$K_t = K_{t-1} + I_{t-1} - CFC_{t-1}$$



# Factors of production: Physical capital


Existing stock

$K_{t-1}$


Investment

$I_{t-1}$

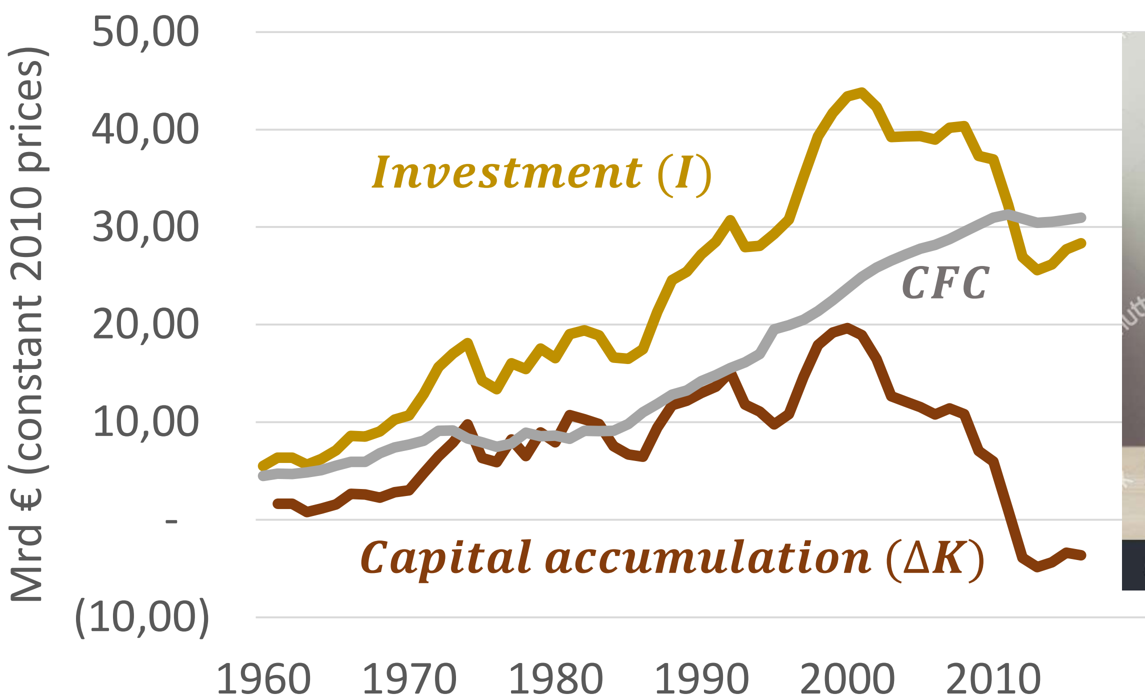

Consumption of fixed capital

$CFC_{t-1}$

Annual capital stock for personal computers

$K_t$

# Factors of production: Physical capital





Perpetual Inventory Method (PIM):

$$K_t = K_{t-1} + I_{t-1} - CFC_{t-1}$$

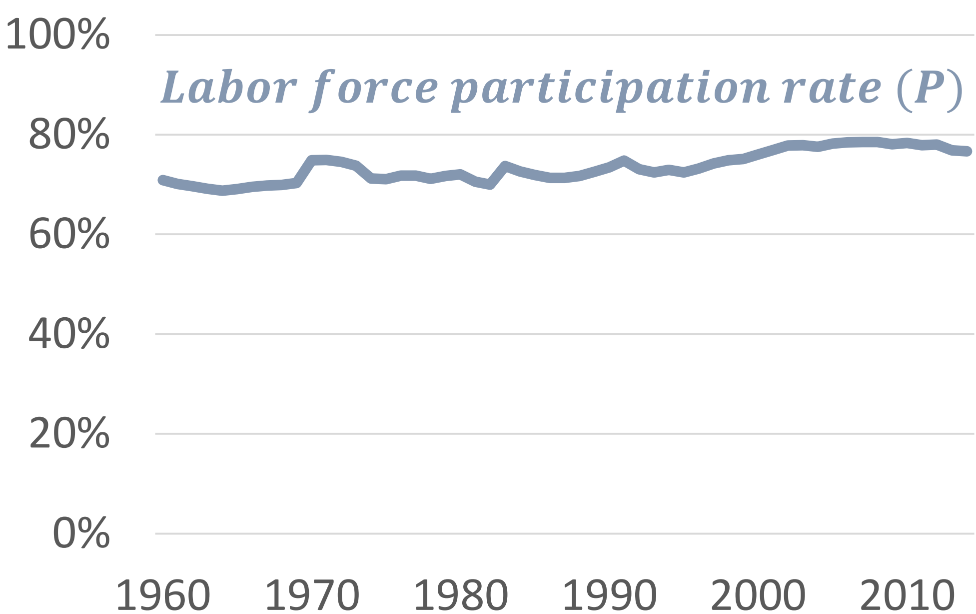
$$\Delta K_t = K_t - K_{t-1} = I_{t-1} - CFC_{t-1}$$

# Factors of production: Human labor

## Working age population (15-64)

# Factors of production: Human labor

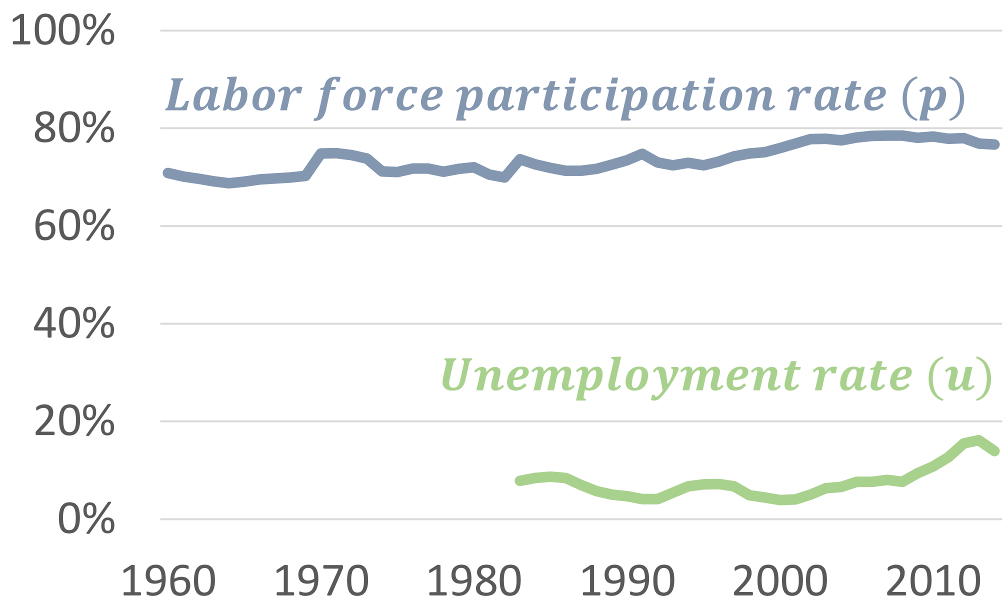

Labor force is the pool of workers (employed and unemployed) available to the economy




Labor force participation rate for Portugal (slightly increasing, in the range 70-80%)

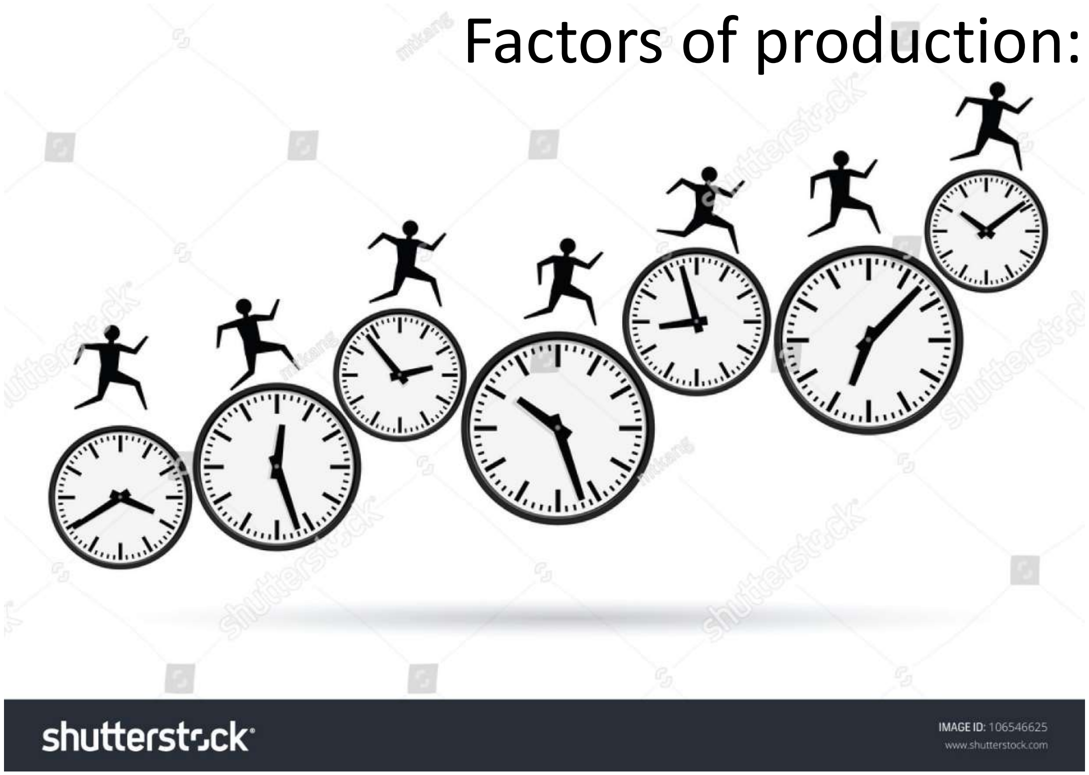
# Factors of production: Human labor


Unemployment corresponds to individuals available to work but not currently employed

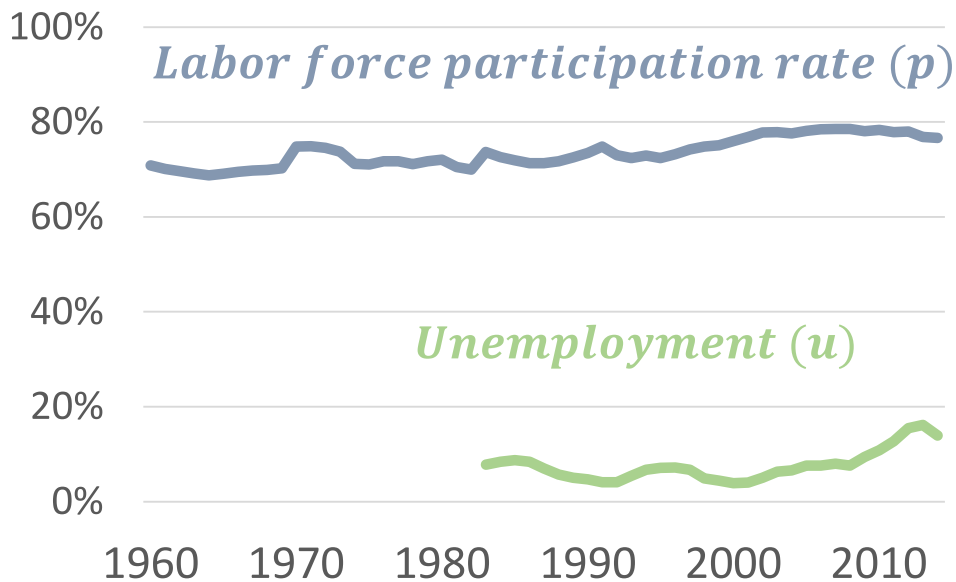



Unemployment rate for Portugal

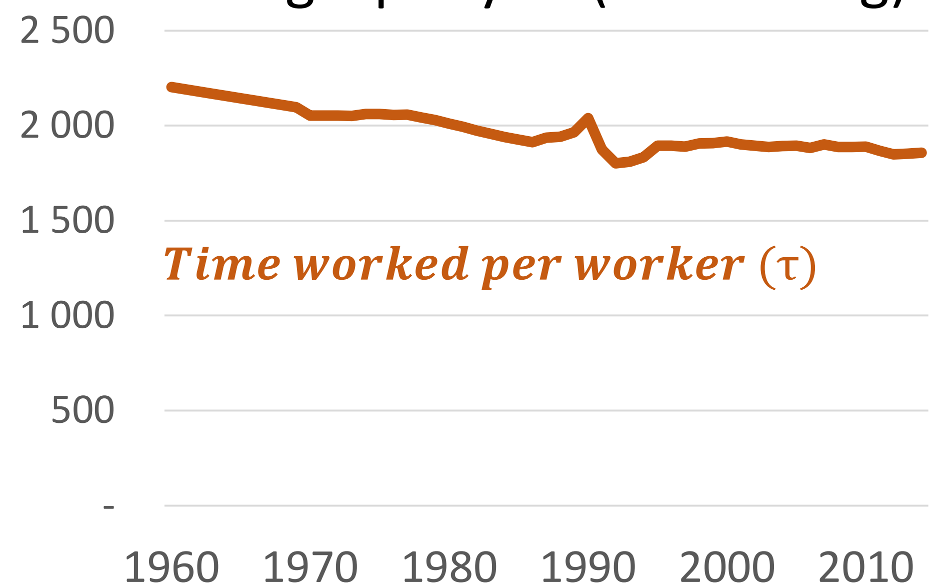
# Factors of production: Human labor



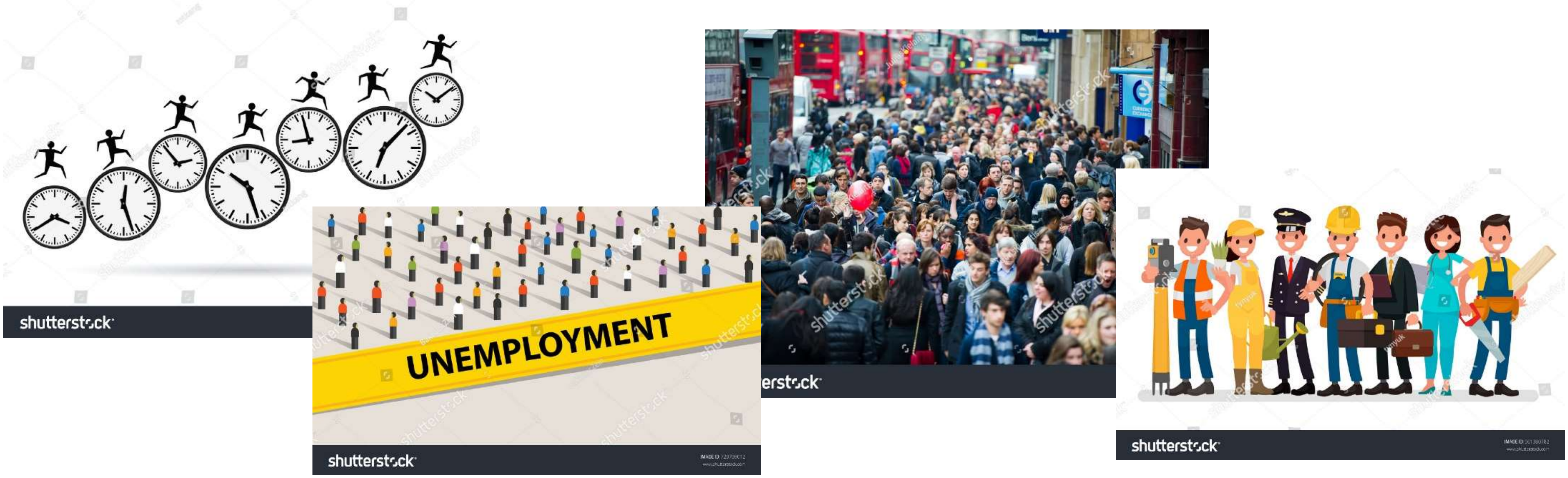

Hours worked vary for different individuals (e.g. part-time vs. full-time)



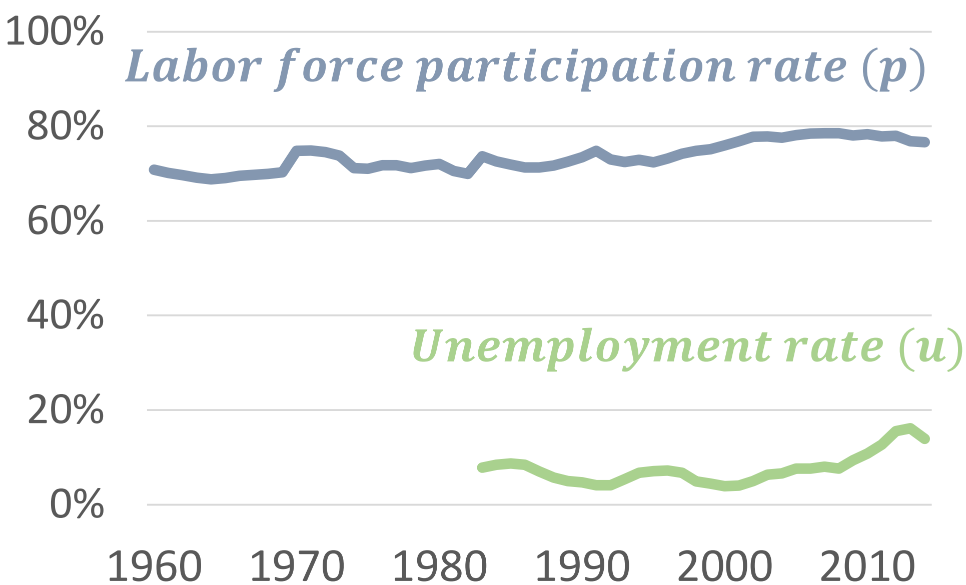

Hours worked per worker in Portugal per year(decreasing)

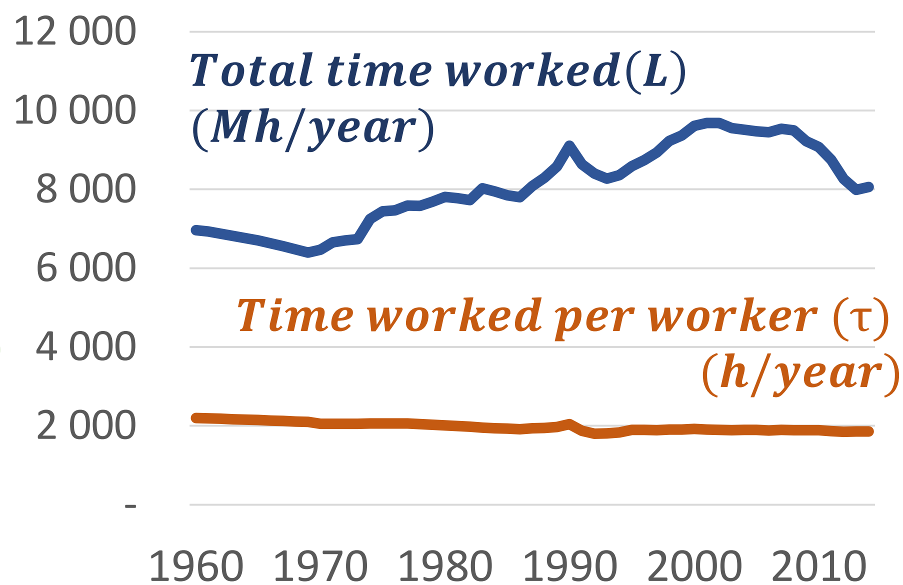


# Factors of production: Human labor

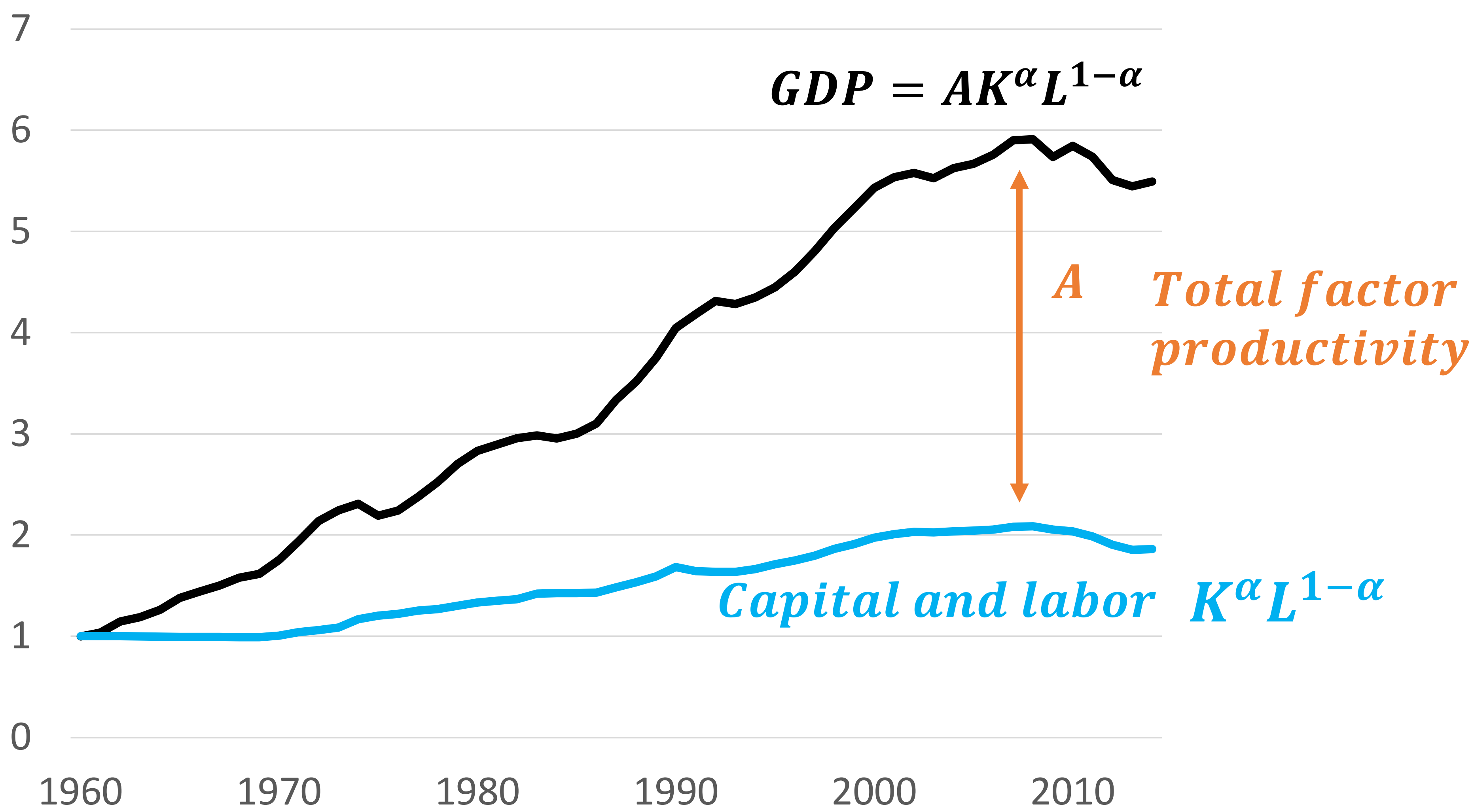



$$L = \tau \times (1 - u) \times p \times Pop_{15-64}$$



# Total Factor Productivity



# Total Factor Productivity (TFP): growth accounting

$$GDP = AK^{\alpha}L^{1-\alpha}$$

$$\frac{dGDP}{dt} = \frac{dA}{dt}K^{\alpha}L^{1-\alpha} + A\frac{d(K^{\alpha})}{dt}L^{1-\alpha} + AK^{\alpha}\frac{d(L^{1-\alpha})}{dt}$$

$$\frac{dGDP}{dt} = \frac{dA}{dt}K^{\alpha}L^{1-\alpha} + \alpha A\frac{dK}{dt}K^{\alpha-1}\,L^{1-\alpha} + (1-\alpha)AK^{\alpha}\frac{dL}{dt}L^{1-\alpha-1}$$

$$\frac{\frac{dGDP}{dt}}{GDP} = \frac{\frac{dA}{dt}}{A} + \alpha\frac{\frac{dK}{dt}}{K} + (1-\alpha)\frac{\frac{dL}{dt}}{L}$$

$$g_{GDP} = g_A + \alpha g_K + (1-\alpha)g_L$$

<u>Growth accounting</u>

**(3.2%)** **(2.0%)** **(1.0%)** **(0.2%)**

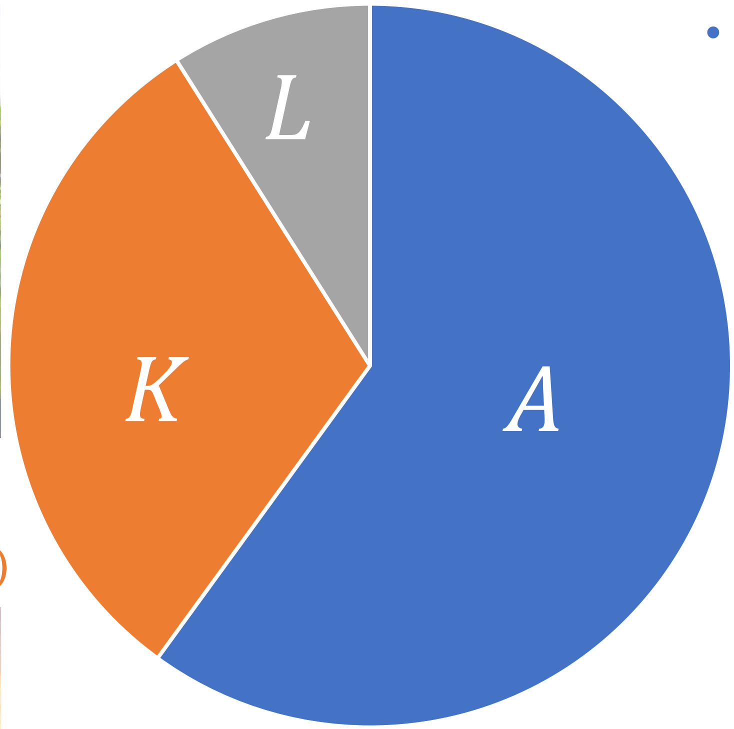
# Contributions to economic growth: Capital, labour and TFP

***Total Factor Productivity*** (63%)

- ***Technical change***
- ***Policy***
- ***Institutions***
- ???

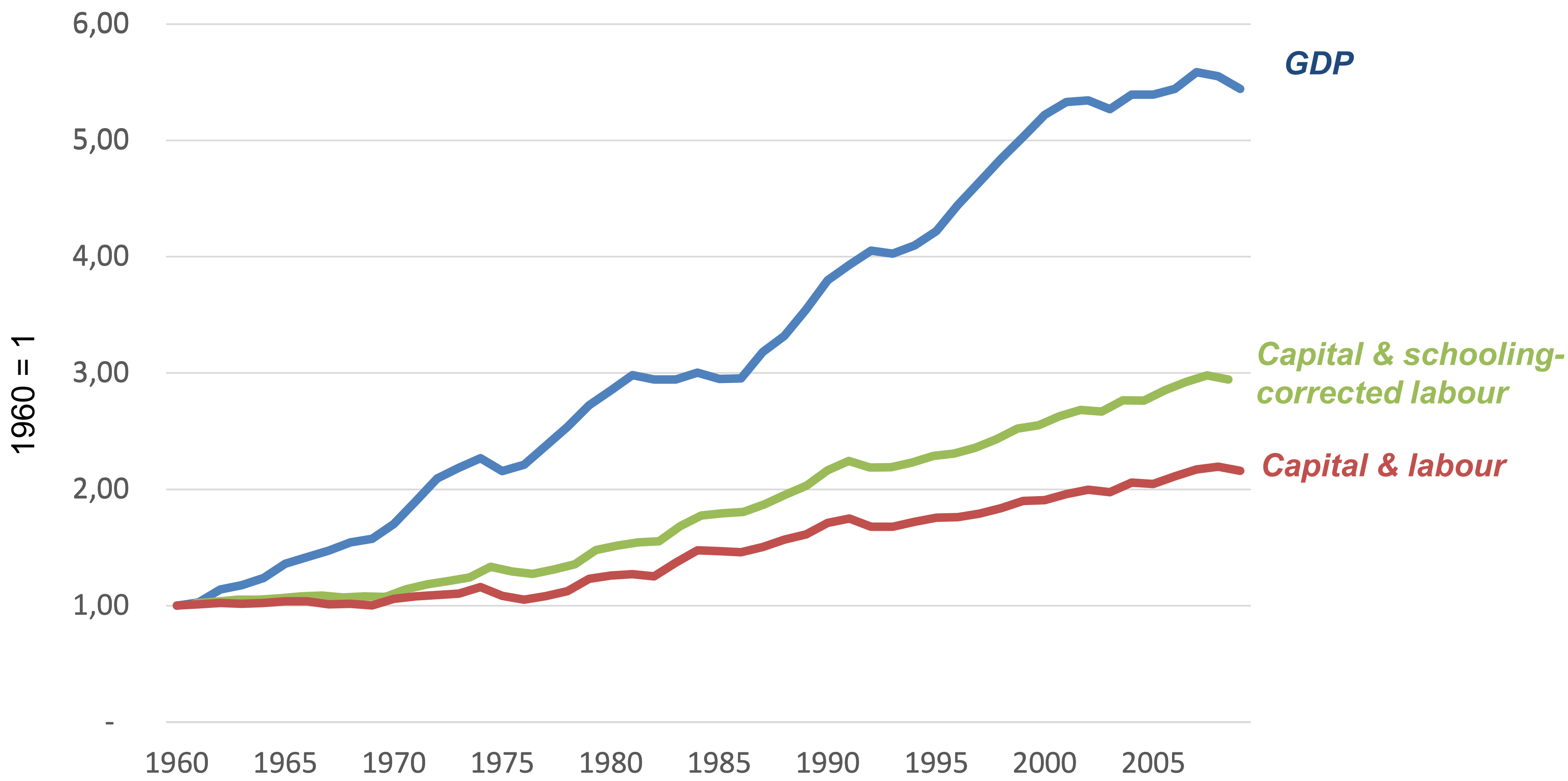
***Labour*** (7%)
(*e.g. Workers*)


***Capital*** (30%)
(*e.g. Machines*)


$$GDP = AK^{\alpha}L^{1-\alpha}$$

# GDP and production factors: quality correction



## The main source of economic growth is essentially unknown

- Economic growth cannot be explained just by the increase in production factors: capital and labour

- Most of economic growth is explained by total factor productivity growth, the Solow residual

- As Abramovitz (1956) said, the Solow residual represents "a measure of our ignorance" of the growth process

- Could energy be an explanatory factor for the Solow residual?

- Let us measure energy considering *useful exergy*

# Energy and its role in economic production and growth

$$GDP = AK^{\alpha}L^{1-\alpha}$$

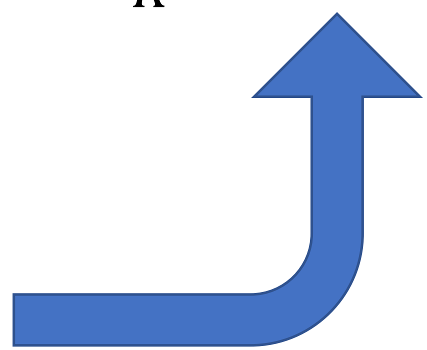
Human labor


$L$

Physical capital


$K$

Energy (?)

# The Laws of Thermodynamics

- First law: in any physical process, energy is conserved.
  - "In nature nothing is created, nothing is lost, everything changes" (Lavoisier).
- Second law: in any physical process, entropy increases.
  - Entropy is not conserved
  - In any physical process, energy is dissipated, i.e., loses its capacity to produce work.

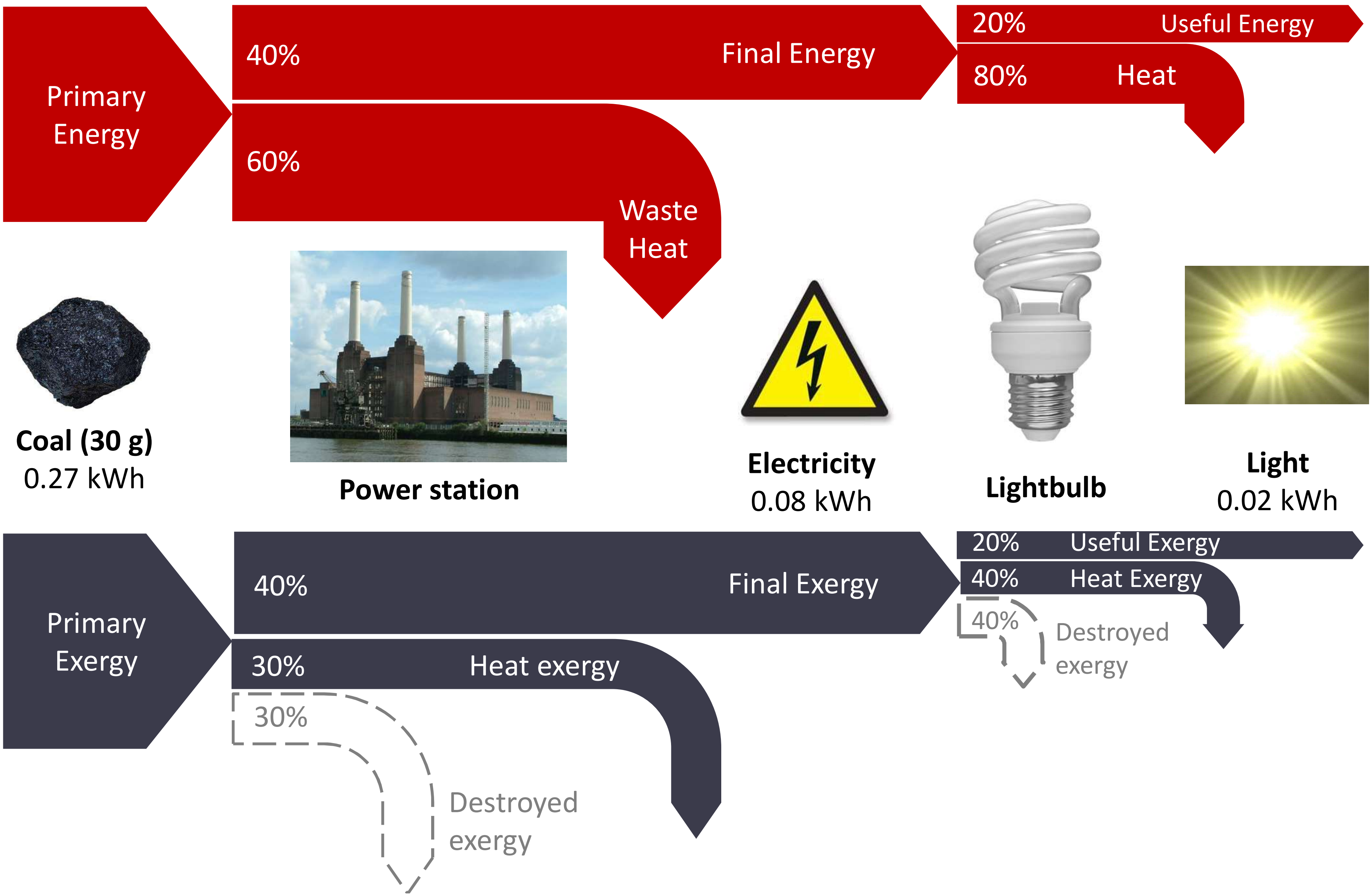
# Why exergy?

- The statement “a lamp consumes energy” is WRONG
- Energy is conserved, so a lamp cannot *consume* energy
- A lamp *degrades* energy, reducing its quality
    - We can do much more with electricity than with heat and light
- So, electricity has a higher *exergy* than heat and light
- The statement a “lamp consumes *exergy”* is RIGHT

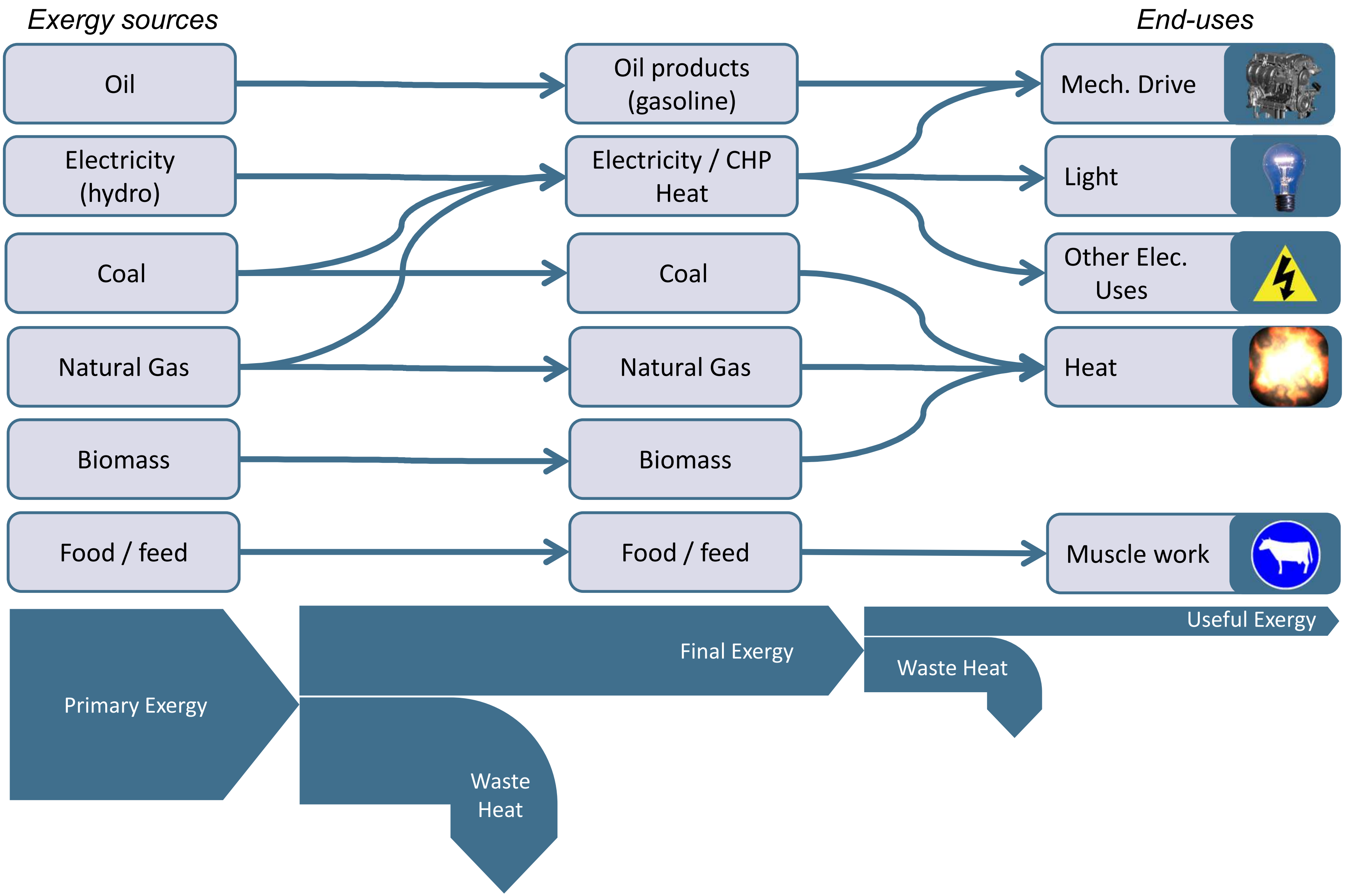
# Why Useful Exergy

- Exergy correctly adds up heat and work
  - Work can be completely converted to heat, but heat cannot be completely converted to work
    - “All energies are equal, but some are more equal than others”
- Exergy destruction expresses the Second Law of Thermodynamics
  - The irreversibility and production of entropy in all physical processes (the Arrow of Time)
- The useful stage of energy transformation is the one closest to the creation of economic value
  - In fact, it is the last one, because after it energy is completely dissipated (exergy is completely destroyed)

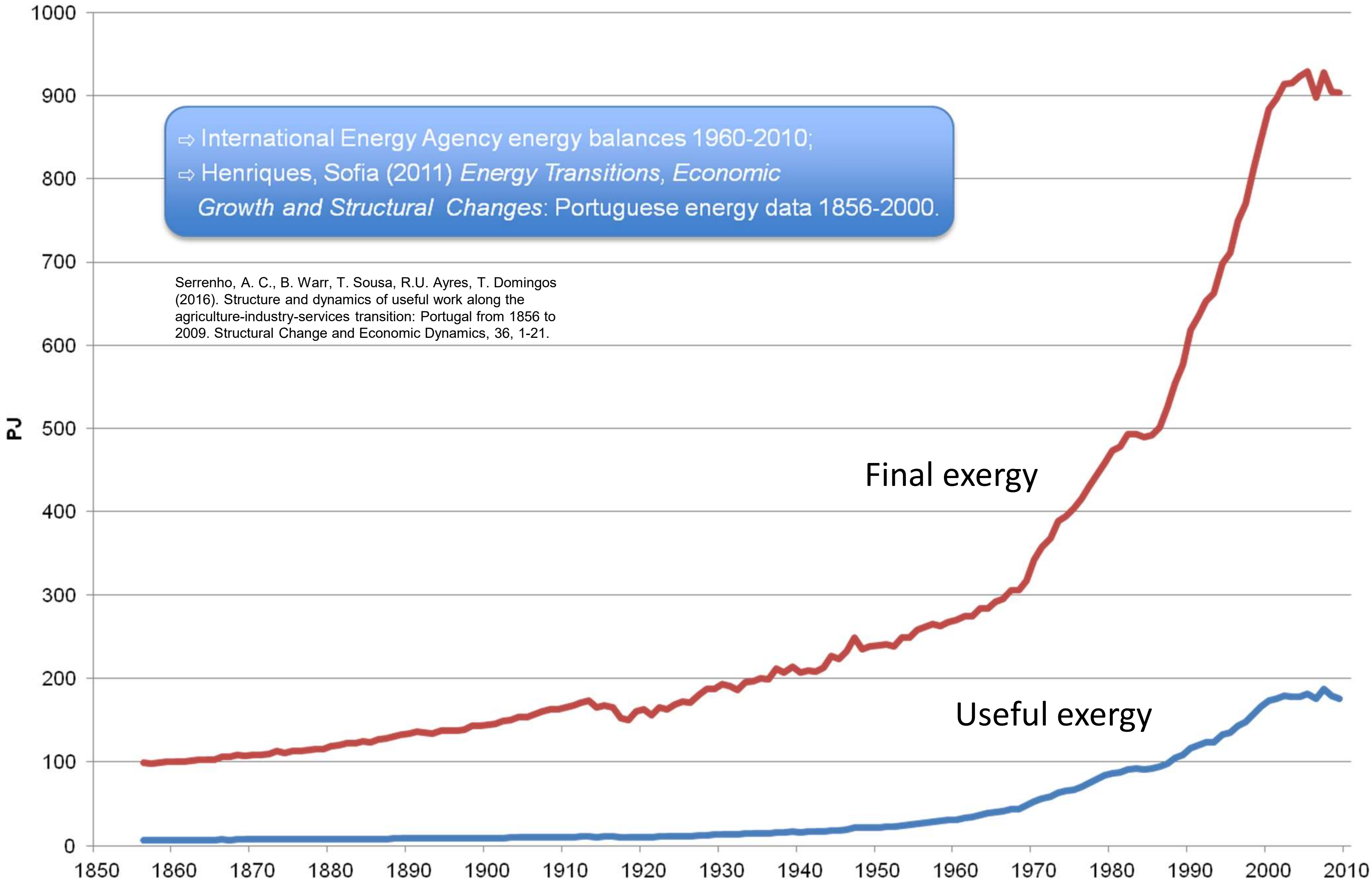
# Primary, Final and Useful Exergy



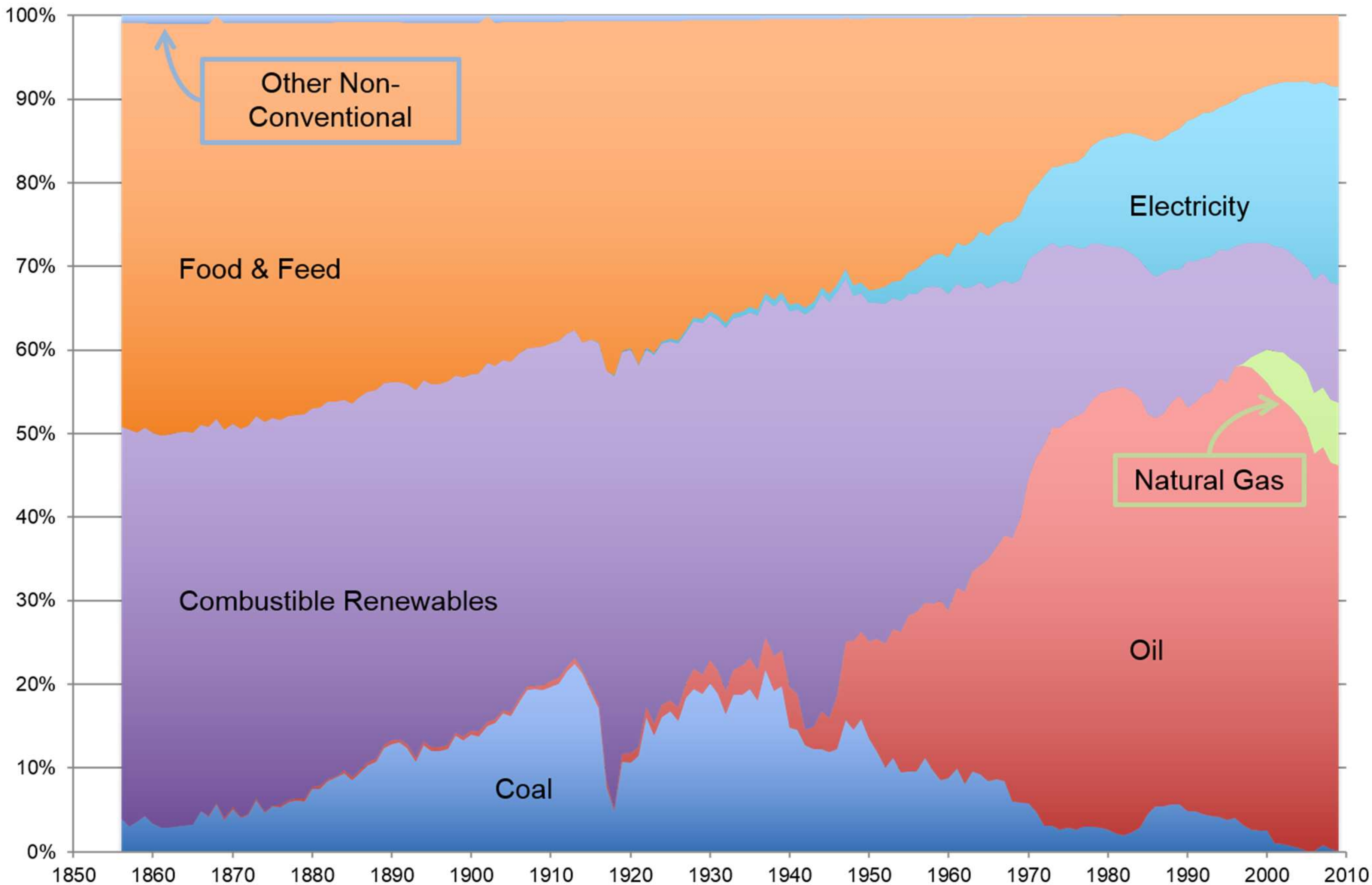
# Exergy carriers & end-uses



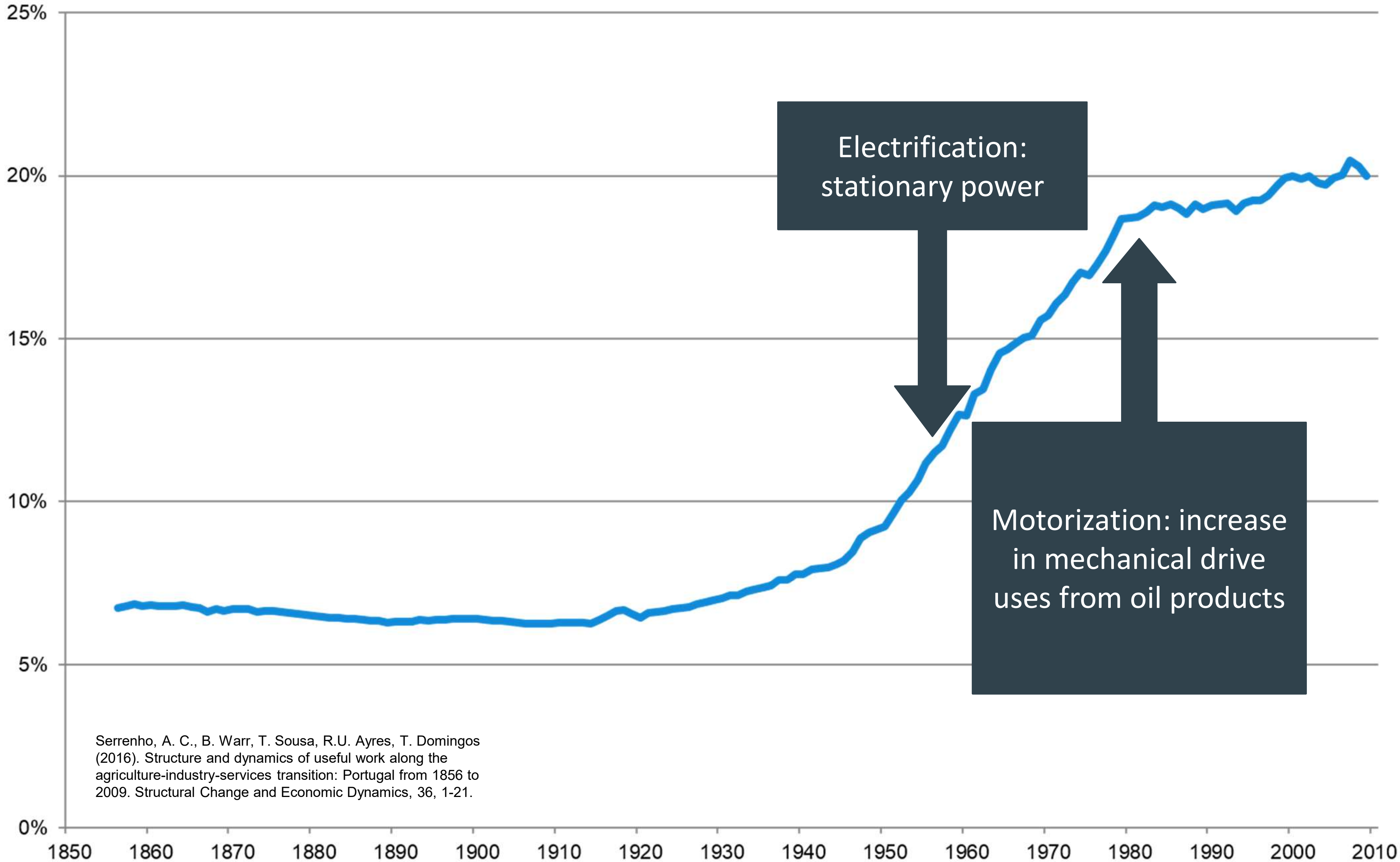
# Final and Useful exergy consumption – Portugal 1856-2009



# Final exergy inputs by carrier – Portugal 1856-2009

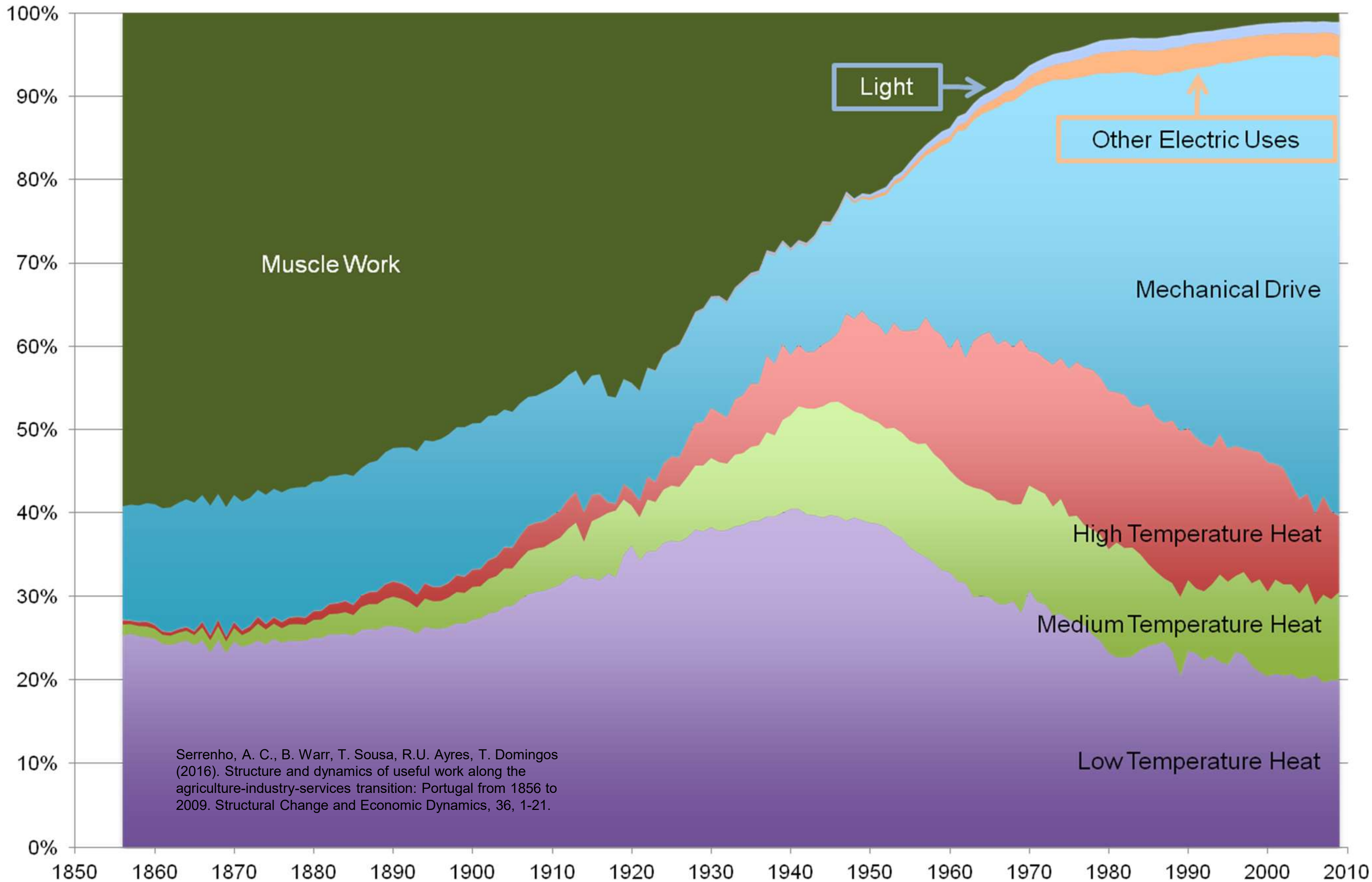


# Aggregate Final-to-Useful efficiency – Portugal 1856-2009

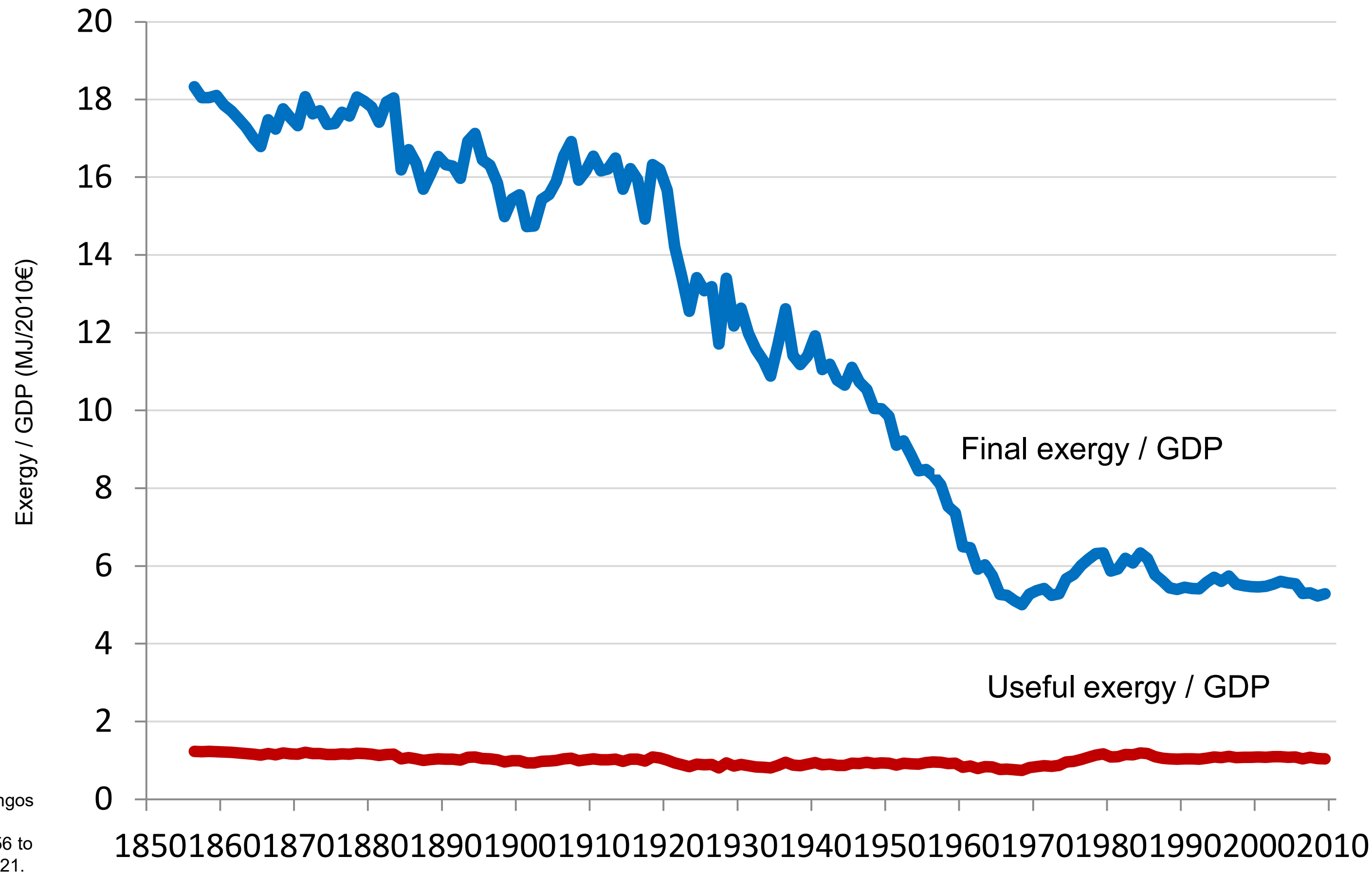



Serrenho, A. C., B. Warr, T. Sousa, R.U. Ayres, T. Domingos (2016). Structure and dynamics of useful work along the agriculture-industry-services transition: Portugal from 1856 to 2009. Structural Change and Economic Dynamics, 36, 1-21.

# Composition of Useful exergy – Portugal 1856-2009



# Final and useful exergy intensities, Portugal 1856-2009

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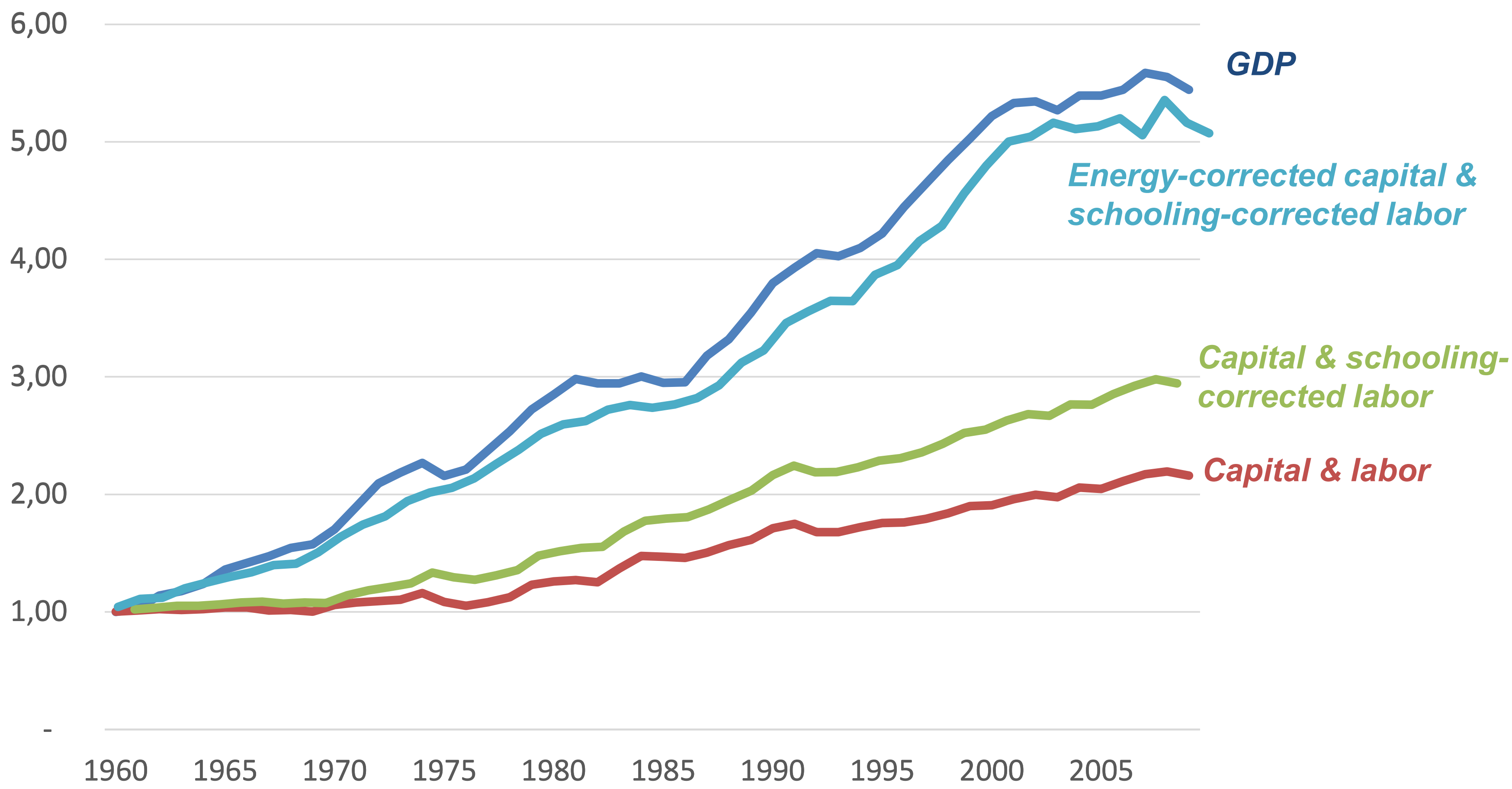
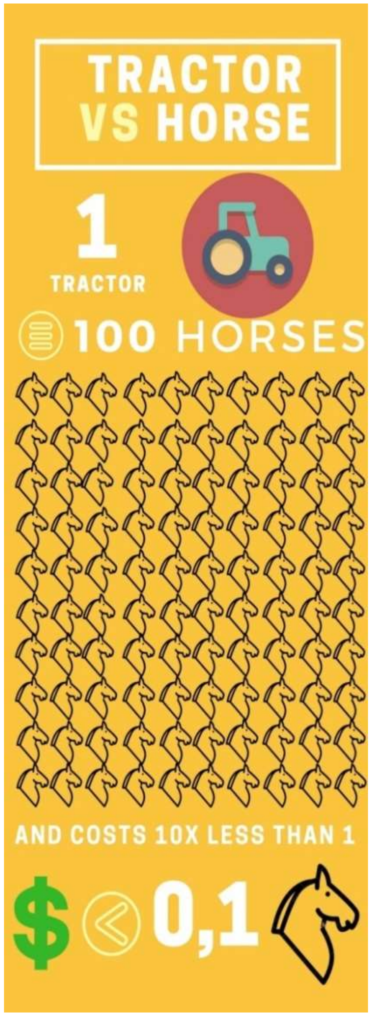
# Energy-corrected capital explains Total Factor Productivity




TRACTOR
VS HORSE
1
TRACTOR
100 HORSES
AND COSTS 10X LESS THAN 1
$
0,1

## Taking stock

- Increases in energy efficiency and delivery of useful exergy are intrinsically related to economic growth
- However, economic growth does not happen just because of increases in energy efficiency, it is associated to a whole "development block".