

# Innovation Efficiency in the European Wood-Processing and Production of Furniture Sectors: A DEA Approach with Undesirable Outputs

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## MOTIVATION

# Why innovation efficiency?

### Innovation drives competitiveness

Innovation is a key source of productivity, industrial resilience and the green transition in the EU.

### Wood and furniture matter

C16 and C31 are core parts of the European bioeconomy: jobs, regional value added, forest-based value chains.

### Activity ≠ results

Many innovating firms do not automatically mean many completed innovations. Some projects are abandoned or suspended.

The key question is not *how much* a country innovates, but **how well** it converts its enterprise base into successful innovation.

## RESEARCH GAP

# What existing studies miss

### DEA is well established for innovation

Used for technological innovation, R&D and innovation-management efficiency at regional, industry and national level (Cruz-Cázares et al., 2013; Durana et al., 2020; Wang et al., 2022).

### But only successes are counted

Studies measure completed innovations; abandoned or suspended projects are ignored, although they are a real source of inefficiency.

### Low- and medium-tech sectors are under-studied

Most DEA innovation studies focus on high-tech industries or whole economies.

## OUR IDEA

Treat unsuccessful innovation as an *undesirable output* that efficient countries should minimise.

# Aim and research questions

To evaluate the **innovation efficiency** of EU countries in wood processing (C16) and furniture manufacturing (C31), explicitly accounting for **unsuccessful innovation**.

01

Which countries convert their enterprise base into completed innovations most efficiently?

02

How did efficiency change across three CIS waves: 2016–18, 2018–20, 2020–22?

03

Does a larger innovation system automatically mean higher efficiency?

# DEA in one sentence

## Decision-making units

Each country is a DMU: it uses inputs to produce outputs.

## Best-practice frontier

DEA builds a frontier from the best-performing countries, without assuming a production function.

## Distance = inefficiency

A country on the frontier is efficient; the further below it, the larger its improvement potential.



Efficiency is **relative**: each country is compared with the best practice observed among its peers, not with a theoretical ideal.

# How the DDF measures efficiency

## Two goals at once

Expand the desirable output (completed innovations) and contract the undesirable one (abandoned or suspended) simultaneously.

## The score $\beta$

The largest proportional move towards the frontier:  $+\beta$  for good output and  $-\beta$  for bad output.

## Reading the score

$\beta = 0$ : on the frontier (efficient).  $\beta = 0.40$ : completed innovations could rise by 40% and abandoned fall by 40% with the same input.

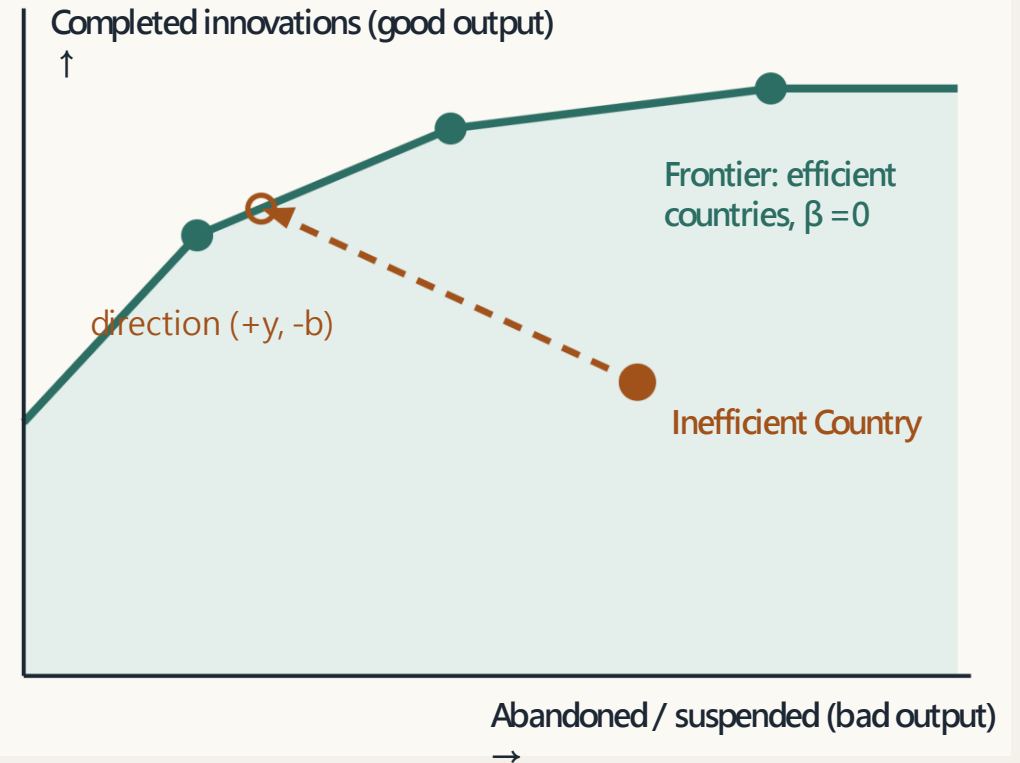


Illustration for a fixed input. A moves up (more completed innovations) and left (fewer abandoned) until it reaches the frontier.

# The model: one input, two outputs

## INPUT (X)

**Enterprise base: number of enterprises**

Eurostat inn\_cis11\_bas, inn\_cis12\_bas, inn\_cis13\_bas

## DESIRABLE OUTPUT (Y)

**Enterprises with completed innovation activities**

Eurostat inn\_cis11\_inact, inn\_cis12\_inact, inn\_cis13\_inact

## UNDESIRABLE OUTPUT (B)

**Enterprises with abandoned or suspended innovation activities**

Eurostat inn\_cis11\_inact, inn\_cis12\_inact, inn\_cis13\_inact

**DMUs:** EU countries + Norway

**Returns to scale:** variable (VRS)

**Software:** Stata 17

## DATA

# Community Innovation Survey, three waves

## CIS 2018

reference period 2016–2018

## CIS 2020

reference period 2018–2020

## CIS 2022

reference period 2020–2022

### C16 • Wood processing

Manufacture of wood and products of wood and cork. **22 DMUs**: 21 EU countries + Norway.

### C31 • Furniture

Manufacture of furniture. **20 DMUs**: Ireland and Luxembourg lack complete data.

Only countries with complete observations for all variables are included, so shares of efficient countries are comparable **within** a sector, not between sectors.

# Why variable returns to scale?

## Constant returns (CRS)

Every country is compared with the most productive one regardless of size. Small systems are penalised for being small.

## Variable returns (VRS) — used here

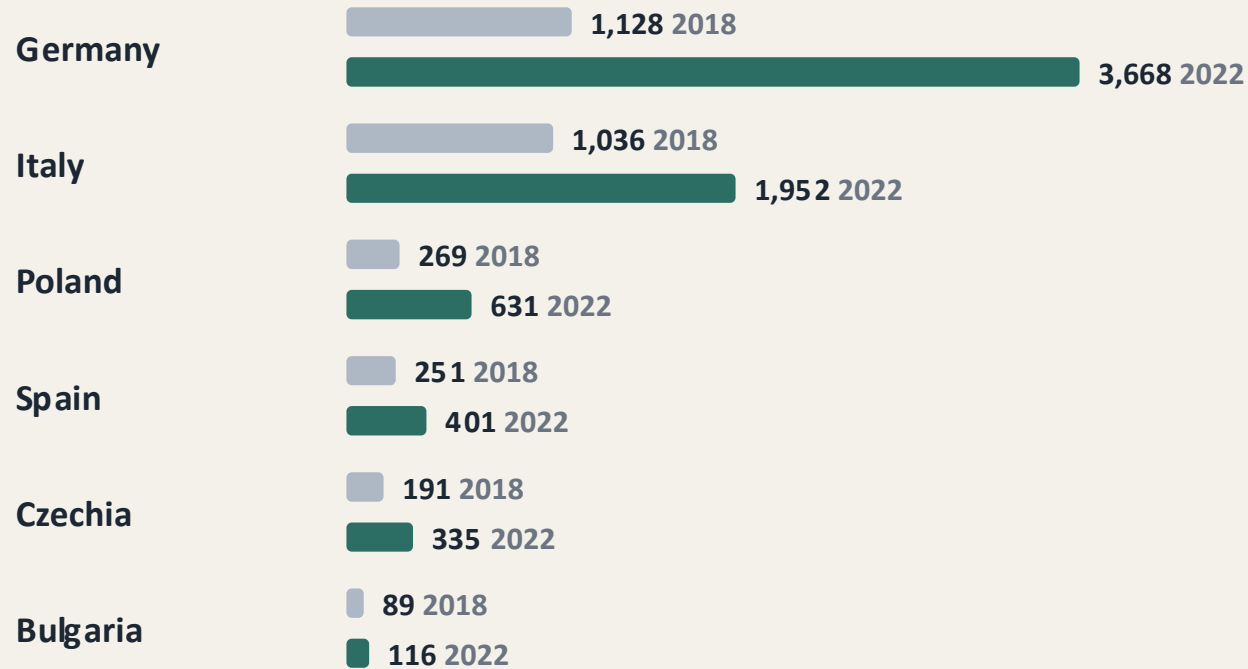
Each country is compared with peers of similar size. Efficiency reflects how well the enterprise base is used, not its absolute scale.



**Side effect:** under VRS the smallest and the largest units often lie on the frontier by construction. This helps explain why both Germany and small countries appear efficient.

# Completed innovations grew

Enterprises with completed innovation activities, CIS 2018 vs CIS 2022



## Leaders expanded

Germany more than tripled; Italy nearly doubled. Both kept unsuccessful projects moderate.

## Smaller systems move slowly

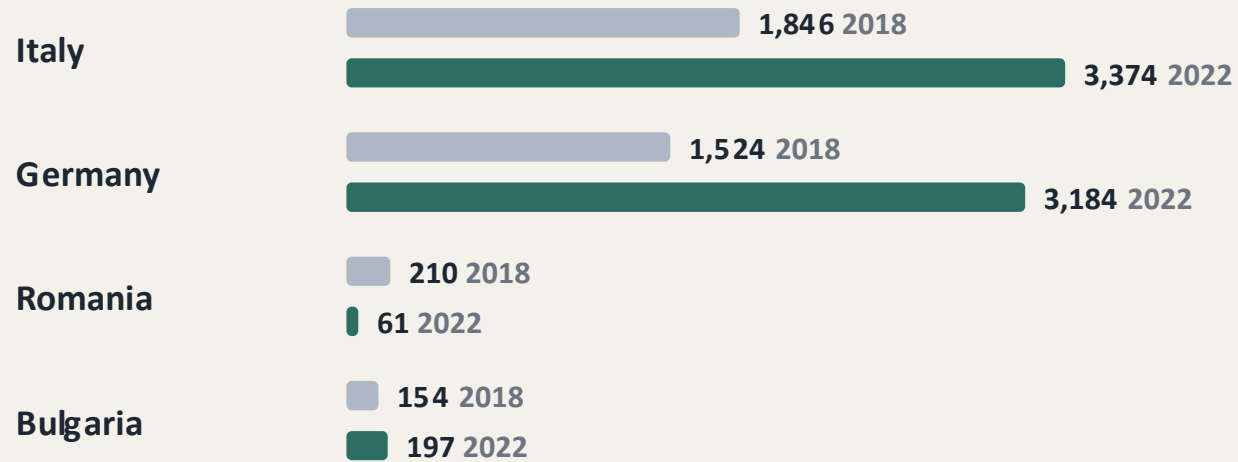
Cyprus, Hungary, Bulgaria and Romania have far fewer completed innovations and more volatility.

## Bulgaria

Completed innovations 89 → 116; abandoned or suspended 9 → 0.

# More innovation, more divergence

Enterprises with completed innovation activities, CIS 2018 vs CIS 2022



## Leaders doubled

Italy 1,846 → 3,374; Germany 1,524 → 3,184.

## Bulgaria improved

Completed 154 → 197; abandoned or suspended 138 → 0.

## Romania fell back

Completed innovations dropped from 210 to 61.

## Greater heterogeneity

Smaller economies differ strongly in their capacity to complete innovation projects.

# Wood processing: radial DDF scores ( $\beta$ )

| Country         | 2016–18 | 2018–20 | 2020–22 | Country    | 2016–18 | 2018–20 | 2020–22 |
|-----------------|---------|---------|---------|------------|---------|---------|---------|
| Belgium         | 0.96    | 0.97    | 0.56    | Ireland    | 0.94    | 0.63    | 0.64    |
| <b>Bulgaria</b> | 0.84    | 0.15    | 0.00    | Italy      | 0.00    | 0.01    | 0.00    |
| Croatia         | 0.00    | 0.00    | 0.21    | Latvia     | 0.76    | 0.22    | 0.72    |
| Cyprus          | 0.96    | 0.43    | 0.14    | Luxembourg | 0.98    | 0.00    | 0.00    |
| Czechia         | 0.53    | 0.60    | 0.53    | Norway     | 0.98    | 0.00    | 0.35    |
| Denmark         | 0.92    | 0.06    | 0.00    | Poland     | 0.28    | 0.26    | 0.00    |
| Finland         | 0.90    | 0.07    | 0.39    | Portugal   | 0.77    | 0.23    | 0.18    |
| France          | 0.00    | 0.00    | 0.96    | Romania    | 0.00    | 0.00    | 0.82    |
| Germany         | 0.00    | 0.00    | 0.00    | Slovakia   | 0.88    | 0.00    | 0.72    |
| Greece          | 0.94    | 0.36    | 0.35    | Spain      | 0.14    | 0.14    | 0.25    |
| Hungary         | 0.00    | 0.36    | 0.60    | Sweden     | 0.00    | 0.00    | 0.00    |

|                        |            |           |           |                   |                                  |
|------------------------|------------|-----------|-----------|-------------------|----------------------------------|
| 0.00 = on the frontier | below 0.25 | 0.25–0.49 | 0.50–0.74 | 0.75+ = large gap | Efficient: 27.3% → 36.4% → 31.8% |
|------------------------|------------|-----------|-----------|-------------------|----------------------------------|

# Furniture: radial DDF scores ( $\beta$ )

| Country         | 2016–18 | 2018–20 | 2020–22 | Country  | 2016–18 | 2018–20 | 2020–22 |
|-----------------|---------|---------|---------|----------|---------|---------|---------|
| Belgium         | 0.00    | 0.00    | 0.27    | Hungary  | 0.00    | 0.63    | 0.45    |
| <b>Bulgaria</b> | 0.54    | 0.00    | 0.00    | Italy    | 0.00    | 0.00    | 0.00    |
| Croatia         | 0.85    | 0.54    | 0.20    | Latvia   | 0.62    | 0.60    | 0.23    |
| Cyprus          | 0.24    | 0.00    | 0.00    | Norway   | 0.37    | 0.52    | 0.18    |
| Czechia         | 0.10    | 0.29    | 0.51    | Poland   | 0.27    | 0.01    | 0.21    |
| Denmark         | 0.87    | 0.00    | 0.00    | Portugal | 0.32    | 0.26    | 0.00    |
| Finland         | 0.75    | 0.36    | 0.00    | Romania  | 0.32    | 0.00    | 0.73    |
| France          | 0.17    | 0.31    | 0.94    | Slovakia | 0.38    | 0.53    | 0.00    |
| Germany         | 0.02    | 0.00    | 0.00    | Spain    | 0.21    | 0.04    | 0.04    |
| Greece          | 0.78    | 0.25    | 0.34    | Sweden   | 0.00    | 0.03    | 0.00    |

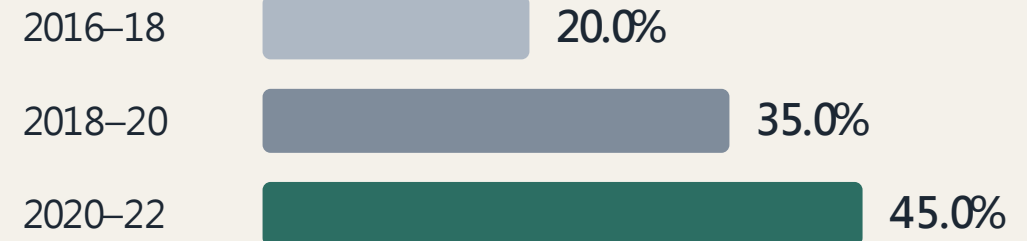
|                        |            |           |           |                   |                            |
|------------------------|------------|-----------|-----------|-------------------|----------------------------|
| 0.00 = on the frontier | below 0.25 | 0.25–0.49 | 0.50–0.74 | 0.75+ = large gap | Efficient: 20% → 35% → 45% |
|------------------------|------------|-----------|-----------|-------------------|----------------------------|

## Share of efficient countries is rising

### C16 · Wood processing (22 DMUs)



### C31 · Furniture (20 DMUs)



More countries reach best practice over time, especially in **furniture**. In wood processing the improvement stalled in 2020–22.

SPOTLIGHT

# Bulgaria: from the bottom to the frontier

0.84 → 0.15 → 0.00

C16 wood processing: DDF score across the three waves

0.54 → 0.00 → 0.00

C31 furniture: on the frontier since 2018–20

89 → 116

C16 enterprises with completed innovations; abandoned 9  
→ 0

154 → 197

C31 enterprises with completed innovations; abandoned  
138 → 0

**Driver:** the fall of abandoned and suspended innovation to zero, together with a moderate rise in completed innovations.

## DISCUSSION

# Four patterns in the results

### Leaders stay efficient

Germany and Italy remain on the frontier in both sectors despite their size.

### Small can be efficient

Sweden, Bulgaria, Denmark, Portugal reach the frontier: size is not a precondition.

### Persistent gaps

Czechia, Hungary, Greece and Belgium keep sizeable scores: room to complete more and abandon less.

### High volatility

France and Romania: efficient in early waves, large gaps in 2020–22 (C16: 0.96 and 0.82).

## CONCLUSIONS

# What we conclude

- 1 Efficiency  $\neq$  scale**  
Innovation efficiency depends on converting the enterprise base into completed innovations, not on the volume of activity.
- 2 Small and large on the same frontier**  
Under VRS, smaller countries such as Bulgaria and Sweden reach best practice alongside Germany and Italy.
- 3 Improvement over time**  
Share of efficient countries: C16 27%  $\rightarrow$  32%, C31 20%  $\rightarrow$  45%.
- 4 Unsuccessful innovation matters**  
Counting abandoned and suspended projects reveals inefficiencies that success-only models miss.

## IMPLICATIONS

# What this means for innovation policy

### **Effectiveness over volume**

Support should reward completed innovations, not only the number of firms starting projects.

### **Support the whole cycle**

Follow-up finance, advice and skills to help firms finish projects instead of abandoning them.

### **Monitor failure**

Track abandoned and suspended innovation as a policy indicator, alongside success rates.

### **Learn from peers**

Countries with gaps can benchmark against efficient peers of similar size, e.g. within Central and Eastern Europe.

# Contribution, limitations and next steps

## Contribution

- Abandoned and suspended innovation modelled as an undesirable output
- DEA innovation analysis extended to low- and medium-tech wood and furniture industries
- Comparison of two sectors across three CIS waves

## Limitations and next steps

- Parsimonious model: one input, two outputs
- VRS puts the smallest and largest units on the frontier more easily
- Zero values in the bad output and CIS reporting differences
- Next: Luenberger productivity change over time; more inputs such as innovation expenditure

# Thank you for your attention!

Questions and discussion

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# Key terms in plain language

## DEA

Non-parametric linear programming method; builds a best-practice frontier from observed data.

## DMU

Decision-making unit: here a country in a given sector and period.

## Radial DDF

Moves good output up and bad output down by the same proportion  $\beta$  of their own levels.

## Direction vector

$g = (y, -b)$ : the country's own outputs, so the score is a percentage.

## Weak disposability

Bad output cannot be cut for free: reducing it may also reduce good output.

## VRS

Variable returns to scale: countries compared with peers of similar size.

# Anticipated questions

## **Why count abandoned projects as bad output?**

They consume resources without results — like emissions in environmental DEA. Ignoring them overstates efficiency.

## **How were zeros in the bad output handled?**

Robustness checks replacing zeros with small values (0.1%, 0.05%, 0.01%) gave identical rankings (Spearman  $\rho = 1$ ).

## **Why not CRS?**

CRS would penalise small systems for size; we want to measure how well each uses its own base.

## **Why is Bulgaria efficient with so few innovations?**

Efficiency is relative to its enterprise base under VRS, and its abandoned projects fell to zero.

## **Why such volatility between waves?**

Three separate survey waves, small counts in small countries and a parsimonious model; trends matter more than single scores.

## **Can scores be compared across sectors?**

Not directly: the frontiers and samples differ (22 vs 20 DMUs).