Innovation efficiency in heterogeneity context: A matter of inputs and outputs or of innovation capabilities?

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OUTLINE

1. Motivation and Objectives
2. Theoretical Arguments
3. Innovation Efficiency and IPR portfolio
4. Monopoly rent-seeking and Ambidexterity
5. Theory and Hypotheses
6. Results
7. Handling Heterogeneity and Algorithm
8. Innovation Strategies Results
9. Conclusions

Motivation and Objectives

- The existing literature in efficiency and productivity analysis presumes that the firms under consideration operate under a unique and, therefore, homogeneous innovation production technology.

- However, firms investing in innovation make strategic decisions regarding the types and amount of resources they devote in relation to the expected innovation returns, given their capabilities and pursuing goals. Therefore, heterogeneity is present in most cases due to a plethora of factors (Dosi et al., 2010; Tsekouras et al., 2016).

- From this respect, the evaluation of the innovation process itself goes beyond the simplistic benchmarking of the resources devoted vis a vis the corresponding innovation output, and therefore firm decisions regarding their strategic decisions should be accounted.

Motivation and Objectives

- Many researchers in Europe use CIS data. Indicatively: Brouwer et al (1999);Catozzella et al (2008);Conte et al (2005);Damijan et al (2017); Dimakopoulou et al (2022).
- Metrics regarding the input and output side of the innovation process very often include qualitative indicators, such as whether the firm has sought external R&D, has collaborated with other external organizations, has introduces a product/process innovation or even if it has applied for a patent or other intellectual property schemes.
- These innovation metrics at the firm level very often are captured by non-continuous indicators which take the value of zero if the firm has -purposefully- decided not to include a specific input in its innovation input mix, has not introduced a specific type of innovation type, or has not applied for any formal intellectual property rights (IPRs).
- The most prominent approach to estimate innovation efficiency is grounded on frontiers methodology. DEA ands SFA.
- However, using non continuous input output variables in DEA and especially in the case of innovation efficiency is not feasible.

Motivation and Objectives

- In this context, we propose a methodological strategy that allows us to fuel the innovation production frontier with additional qualitative information departing from the traditional, and continuous in nature, innovation inputs and outputs.

- In this vein, we modify and extend the DEA model firstly introduced by Banker and Morey, (1986), to incorporate the impact of firms' innovation strategies on their innovation efficiency.

- The implementation of modified DEA model (Banker and Morey, 1986) is illustrated by the innovation efficiency evaluation of the 5 Moderate Innovators, namely Greece, Portugal, Hungary, Lithuania and Croatia from 2012-2014 wave of CIS microdata.

Theoretical Arguments

- We argue that the information conveyed by non-continuous variables depict specific innovation strategies and orientation which is valuable information for estimating unbiased innovation efficiency scores.

- Theoretical argumentation were developed linking firms' differential innovation strategies, as they are reflected in their IPR portfolio and their innovation specialisation, with innovation efficiency trade-offs.

- We endogenize the ranking of innovative firms with respect to specific innovation strategies regarding the diversification of their formal IPR schemes and their innovation orientation towards product and process innovation.

- In this vein, we device a heuristic algorithm that endogenously detects and determines hierarchically structured innovation efficiency clusters corroborating the trade-off relationships between innovation efficiency and innovation strategies.

Innovation Efficiency and IPR portfolio

- Firms invest in innovation in order to secure corresponding innovation rents (Maresch et al., 2016). Formal IPRs i.e., patents, copyrights, trademarks, and designs provide such protection and appropriation of innovation returns.

- In this context, firms are called to make the optimum combination of property rights which serves their strategic performance goals (Di Mimin and Faems, 2013; Agostini et al., 2016; Power and Reid, 2021).

- Firms aiming at gaining monopoly rents from their innovation efforts through IPR protection produce at a suboptimum level, and are required to give up productive efficiency, compared to those firms that aim to deploy their resources and investments so as to directly impact their productive performance (Boldrin and Levine, 2002).

- Firms are required to make a decision on whether they will pursue formal protection schemes following their innovation investments and if they do so then they need to choose among a portfolio of formal means of IPR protection which ones serve both the technology and commercialisation scope of their strategy.

Monopoly rent-seekers and Ambidexterity

- Besides their innovation rent-seeking strategy, firms are also called to decide whether their innovation investments are directed towards the development of new products and/or the improvement of current production processes.

- The notion of ambidexterity, i.e., balancing between innovation exploration and exploitation, broadly describes a firm’s efforts to simultaneously mitigate the tensions caused by the demands of different activities in a trade-off situation (Rothaermel and Alexandre, 2009).

- The trade-offs between innovation exploration and exploitation are manifested as tensions between firms’ focus on (future) long-term vs (present) short-term returns from their innovation investments, competing resources and the need for organisational stability vs the imperative organisational adaptability (Lavie et al., 2010).

- Given that monopoly rent seekers have already given up innovation efficiency to implement their monopoly rent-seeking strategy, pursuing an ambidextrous innovation strategy, i.e., both exploration and exploitation, will further impact their innovation efficiency.

- Firms' strategic decision may have an incurring cost on firms’ innovation efficiency and that cost depends on the overall innovation rent-seeking strategy which in turn, greatly determines how firms’ resources are best allocated to serve firms’ strategic goals.

Theory and Hypotheses

- H1: The incorporation of innovation strategy orientation substantially increases the discriminatory power of the efficiency measurement.

- H2: The IPR - innovation efficiency dilemma: balancing between monopoly and competitive rents.
  a) Firms with lower levels of innovation efficiency are focused on securing monopoly rents from an augmented IPR portfolio.
  b) Firms with higher levels of innovation efficiency are more focused in attaining competitive rents from their innovation outputs.

- H3: Innovation exploration and exploitation strategies and the innovation efficiency trade-off.
  a) Competitive rent seeking firms adopt separately or jointly exploitation and exploration innovation strategies only if the trade-offs in terms of innovation efficiency are not significantly high.
  b) Monopoly rent seeking firms which adopt both exploration and exploitation innovation strategies have lower levels of innovation efficiency.
  c) Monopoly rent seeking firms which adopt only exploration innovation strategies have higher levels of innovation efficiency.

Data Envelopment Analysis

CDEA DEA model , input oriented

Efficiency = Min θ

s.t.

$$\sum_{1}^{n} \lambda_j \cdot x_j \leq \theta \cdot x_{r_0}$$

$$\sum_{1}^{n} \lambda_j \cdot y_{r_j} \geq y_{r_0}$$

$$\sum_{1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \ \forall \ j = 1, \dots, r_0, \dots N$$

ISDEA model , input oriented , with categorical inputs variables

Efficiency = Min θ

s.t.

$$\sum_{1}^{n} \lambda_j \cdot x_j \leq \theta \cdot x_{r_0}$$

$$\sum_{1}^{n} \boldsymbol{\lambda_j d_{m_j}^{(\delta)}} \leq \boldsymbol{d_{mr_0}^{(\delta)}}$$

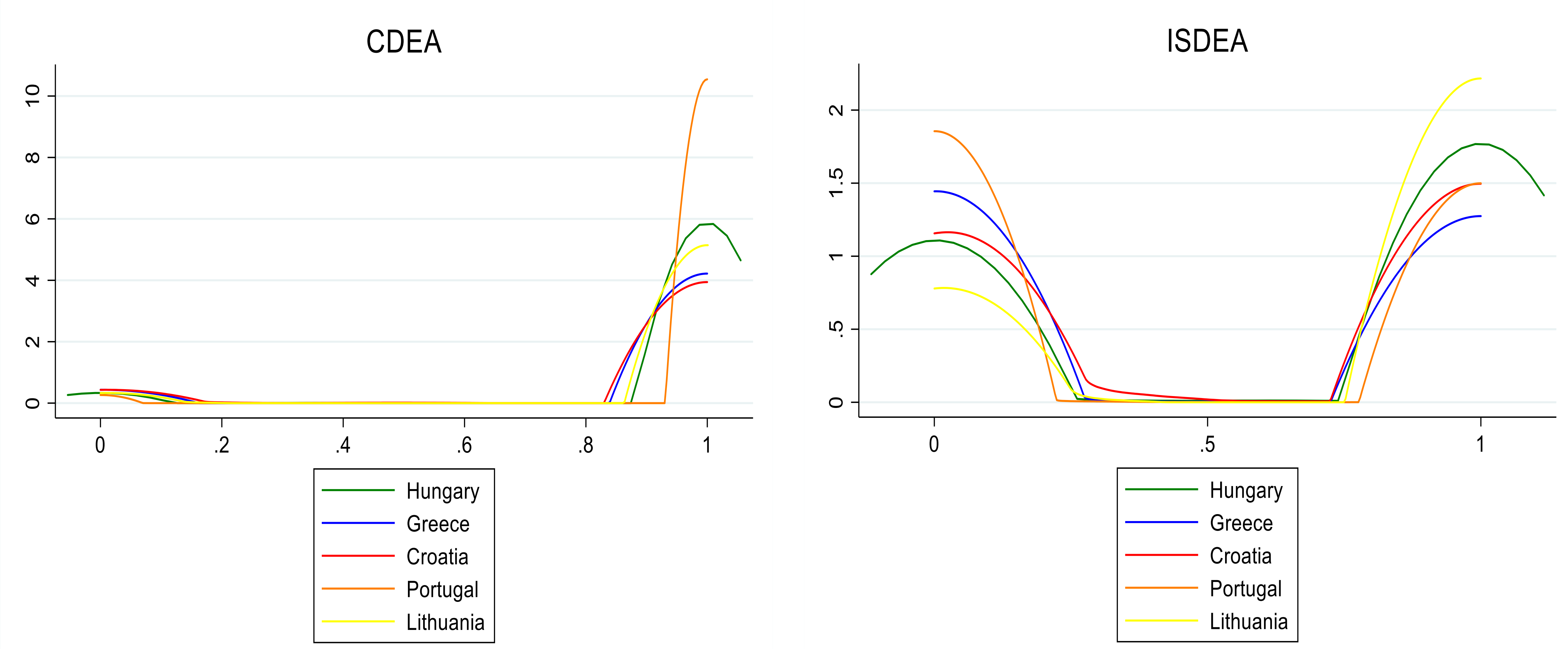
$$\sum_{1}^{n} \boldsymbol{\lambda_j z_{l_j}^{(k)}} \leq \boldsymbol{z_{lr_0}^{(k)}}$$

$$\sum_{1}^{n} \lambda_j \cdot y_{r_j} \geq y_{r_0}$$

$$\sum_{1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \ \forall \ j = 1, \dots, r_0, \dots N$$

With and without innovation strategy



Differences between CDEA and ISDEA innovation efficiency distributions

		Croatia (HR)	Greece (EL)	Hungary (HU)	Lithuania (LT)	Portugal (PT)
	Number of firms: I	559	640	766	533	1,800
CDEA	Average $IEff_k$	0.90	0.91	0.95	0.94	0.98
	(Std. Deviation)	(0.30)	(0.29)	(0.23)	(0.24)	(0.15)
	% of I firms with IEff = 1	89.27%	90.31%	76.37%	92.87%	96.11%
ISDEA	Average $IEff_k$	0.56	0.47	0.60	0.74	0.45
	(Std. Deviation)	(0.48)	(0.50)	(0.49)	(0.43)	(0.50)
	% of I firms with IEff = 1	54.56%	46.72%	59.79%	67.92%	40.67%
WMPSR (p-value)		13.85 (0.00)	17.14 (0.00)	16.19 (0.00)	11.44 (0.00)	31.12 (0.00)

- Based on CDEA efficiency scores, most of the examined firms are identified as fully innovation efficient.
- The dispersion of the innovation efficiency scores is substantially increased and a great portion of firms which were originally identified as fully efficient by the conventional DEA, have moved to the inefficiency zone of the ISDEA innovation frontier.
- Using Wilcoxon Matched Pair Sign Rank we confirm that the distributions of innovation efficiency under CDEA and ISDEA respectively are quite different and ISDEA increases substantially the discriminatory power of the benchmarking process.

Handling Heterogeneity

- The layers of heterogeneity with respect to innovation efficiency are inextricably linked with firms' strategy differential preferences.

- In this vein, we employ a step-by-step process which allows :

    (i) to test if and how many heterogeneous innovation efficiency groups exist,

    (ii) to determine the boundaries of each group,

    (iii) to investigate the role of innovation strategies in assigning firms to specific groups.

Handling Heterogeneity

$$\text{APP} = \frac{\text{number of the firm's IPR applications}}{\text{total number of IPR applications}}$$

$$\text{AMB} = \begin{cases} 1, \text{if a process innovation is introduced} \\ 0, \text{only product innovation is introduced} \end{cases}$$

APP index

- It holds that, $0 \leq \text{APP} \leq 1$.
- Values close to one indicate a heavier orientation towards monopoly rent-seeking innovation strategy, while values close to zero indicate that the firm is more inclined towards a competitive rent-seeking innovation strategy.

AMB index

- Value equal to one indicate the firm's decision to become ambidextrous.

Two group of firms, s and p, identified as distinct in terms of their innovation efficiency, are heterogenous with respect to the innovation strategies regarding appropriability conditions if:

$$\text{D}_{\text{SP}}^{\text{APP}} = \text{APP}_{\text{s}} - \text{APP}_{\text{p}} \neq 0$$

Heterogeneity with respect to innovation ambidexterity implies:

$$\text{D}_{\text{SP}}^{\text{AMB}} = \text{AMB}_{\text{s}} - \text{AMB}_{\text{p}} \neq 0,$$

where s and p groups may be heterogeneous with respect to both innovation strategy preferences, or only to one, or to be homogeneous .

Algorithm for testing the innovation strategy and innovation efficiency

Stage 1: Efficiency Scores Calculation

1. ISDEA innovation efficiency estimation.

Stage 2: Firm's Clustering

2.1. Using the Silhouette method, the optimal number of clusters k within the efficient frontier is determined.

2.2. Each group's borders are determined by k-means clustering approach.

2.3. Incorporate the examined firms in one of the k groups specified.

2.4. Conduct ISDEA for each k clusters specified.

Stage 3: Heterogeneity testing

3.1. Calculate the D^{APP} and D^{AMB} indices for each specified group.

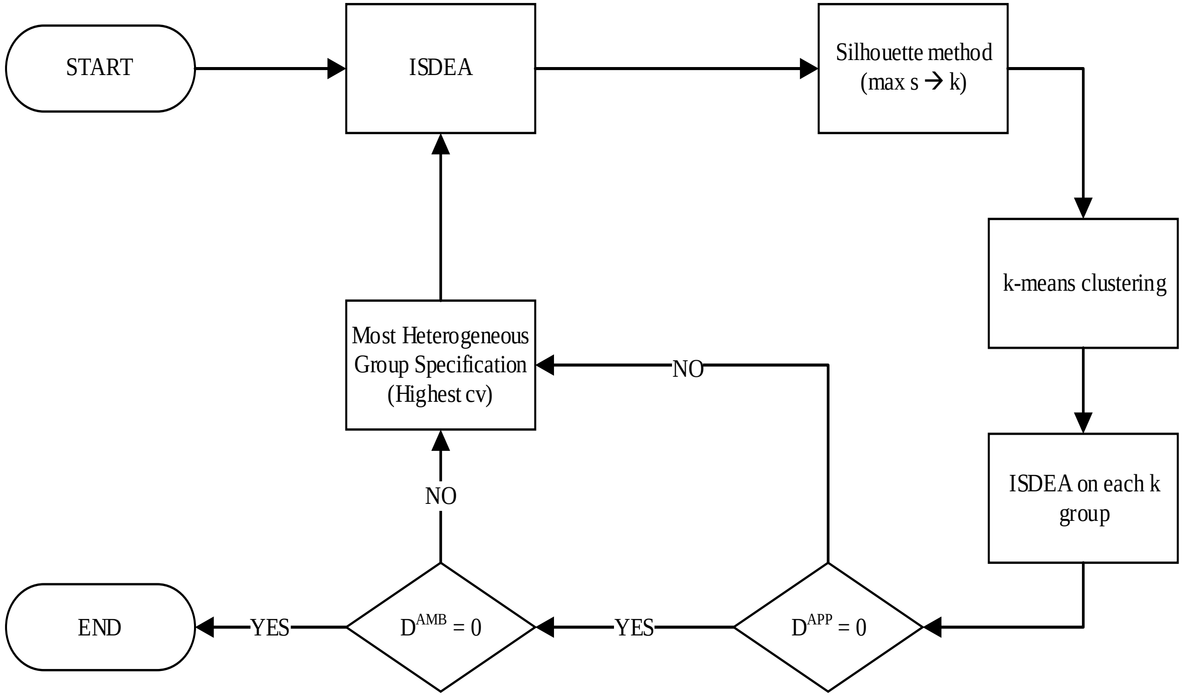
3.2. Test that D^{APP} and D^{AMB} are statistically equal to zero.

3.3. If D^{APP} and D^{AMB} are both statistically non-significant, the algorithm is terminated; else, proceed to stage 4.

Stage 4: Most heterogenous group specification

4.1. Calculate the coefficient of variation (cv) for each group and identify the group with the highest cv.

4.2. Repeat Stages 1 to 3 for the specified group only.



First level clustering

	HR		EL		LT		HU		PT	
	Low IEff	High IEff	Low IEff	High IEff	Low IEff	High IEff	Low IEff	High IEff	Low IEff	High IEff
	$I_{l,1}^{HR} = 250$	$I_{h,1}^{HR} = 309$	$I_{l,1}^{EL} = 340$	$I_{h,1}^{EL} = 300$	$I_{l,1}^{LT} = 141$	$I_{h,1}^{LT} = 392$	$I_{l,1}^{HU} = 296$	$I_{h,1}^{HU} = 470$	$I_{l,1}^{PT} = 997$	$I_{h,1}^{PT} = 803$
Avg IEff	0.25	0.99	0.14	0.99	0.22	0.99	0.23	0.97	0.24	0.98
(Std Dev)	(0.33)	(0.03)	(0.28)	(.09)	(0.32)	(0.07)	(0.36)	(0.16)	(0.41)	(0.12)
APP	0.07	0.04	0.12	0.06	0.09	0.04	0.12	0.05	0.10	0.06
AMB	0.91	0.87	0.94	0.89	0.95	0.91	0.78	0.75	0.91	0.89
cv	1.32	0.03	2.02	0.09	1.45	0.07	1.56	0.16	1.71	0.12
D^{APP}	0.08		0.17		0.15		0.19		0.10	
(p-value)	(0.37)		(0.00)		(0.02)		(0.00)		(0.00)	
D^{AMB}	0.09		0.08		0.08		0.07		0.04	
(p-value)	(0.22)		(0.31)		(0.48)		(0.21)		(0.42)	
Number of firms for clustering	-		340		141		296		997	
Number of groups	-		2		2		2		2	
$I_{l,2}^{c}$	-		304		116		244		773	
(Average S)			(0.78)		(0.75)		(0.77)		(0.93)	
$I_{h,2}^{c}$	-		36		25		52		224	
(Average S)			(0.90)		(0.93)		(0.93)		(0.98)	

- The low efficiency group exhibits significantly higher values of the APP index compared to the corresponding value of the high efficiency group.
- In all the examined countries the D^{AMB} parameter is not different than zero.
- In all country cases, except Croatia, we deduce that the low innovation efficiency group follows an innovation strategy oriented towards a more augmented IPR portfolio.
- Firms in the high innovation efficiency group are less inclined to formally protect their innovation investments and pursue innovation yields following a short-term competition strategy.
- The cv value for all cases, suggests that the low innovation efficiency group exhibits higher intra-group heterogeneity, and therefore, firms that have adopted a monopoly rent-seeking innovation strategy should be further investigated for additional heterogeneity.

Second level clustering

	EL		LT		HU		PT	
	Low IEff $I^{EL}_{l,2} = 304$	High IEff $I^{EL}_{h,2} = 36$	Low IEff $I^{LT}_{l,2} = 116$	High IEff $I^{LT,2}_{h,2} = 25$	Low IEff $I^{HU}_{l,2} = 244$	High IEff $I^{HU}_{h,2} = 52$	Low IEff $I^{PT}_{l,2} = 773$	High IEff $I^{PT}_{h,2} = 224$
Avg IEff	0.22	0.93	0.35	0.85	0.26	0.97	0.32	0.86
(Std Dev)	(0.28)	(0.14)	(0.37)	(0.21)	(0.33)	(0.10)	(0.43)	(0.34)
APP	0.13	0.12	0.10	0.06	0.11	0.13	0.10	0.08
AMB	0.96	0.78	0.99	0.76	0.80	0.72	0.95	0.79
cv	1.27	0.15	1.06	0.25	1,27	0.10		
D^{APP}	0.13		0.16		0.04		0.06	
(p-value)	(1.00)		(0.68)		(1.00)		(0.52)	
D^{AMB}	0.36		0.45		0.15		0.31	
(p-value)	(0.00)		(0.00)		(0.25)		(0.00)	
Number of firms for clustering	304		116		-		224	
Number of groups (s max)	2 (0.79)		2 (0.84)		-		2 (0.97)	
$I^{c}_{l,3}$	255		75		-		548	
$I^{c}_{h,3}$	(49)		(41)				(225)	

- In the cases of Greece, Latvia, and Portugal:

I. monopoly rent-seeking firms with lower efficiency levels are more oriented towards innovation ambidexterity.

II. Monopoly rent seekers which are clustered in the high innovation efficiency group opt for a specialisation in product innovation only.

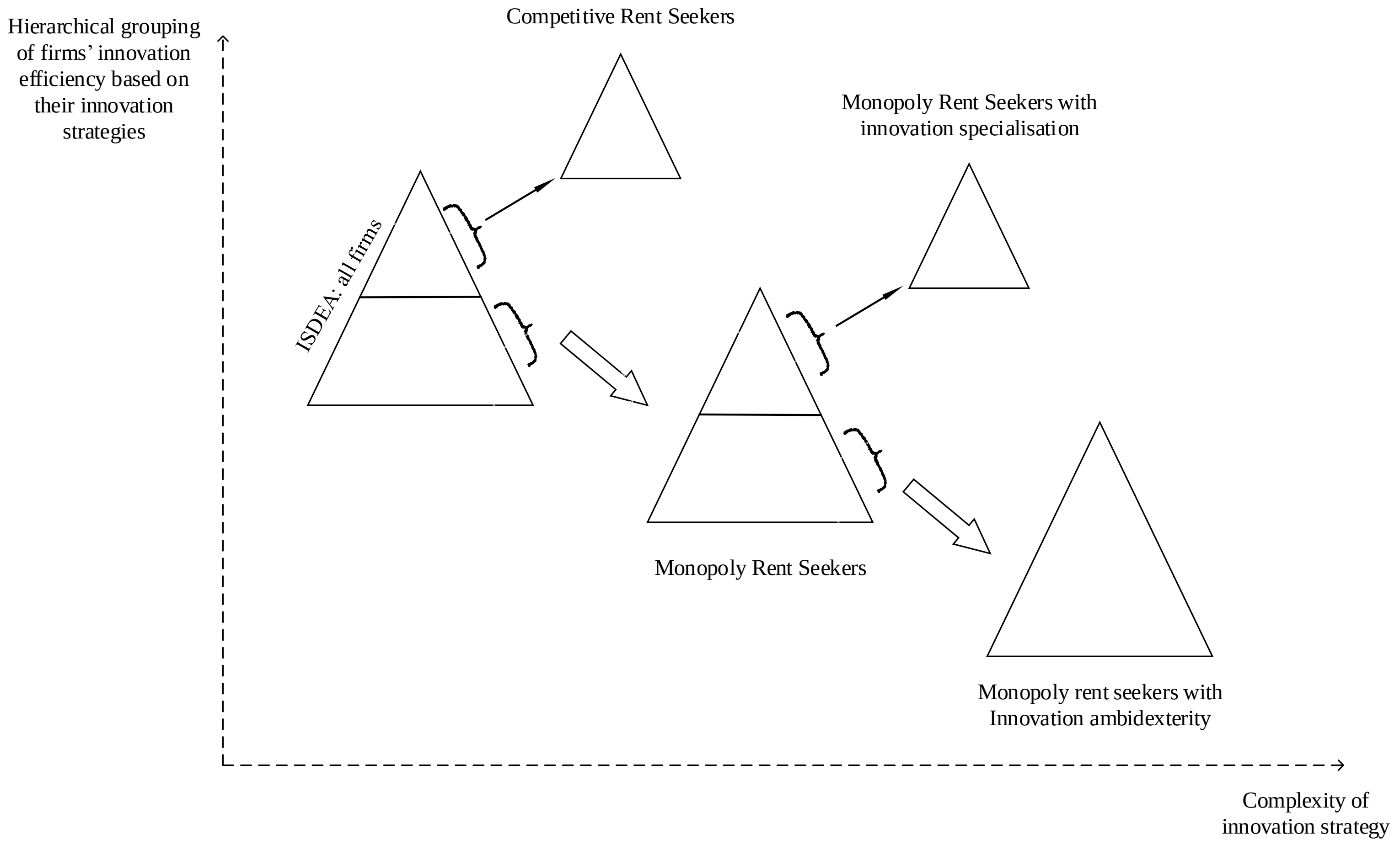
- Hungarian monopoly rent-seeking firms are not further differentiated with respect to innovation ambidexterity, as the non-significance of D^{APP} and D^{AMB} statistics indicate.
- The low innovation efficiency groups should be explored for heterogeneity in innovation efficiency as indicated by cv value.

Third level clustering

	EL		LT		PT	
	Low IEff $I^{EL}_{l,4} = 255$	High IEff $I^{EL}_{h,4} = 49$	Low IEff $I^{LT}_{l,4} = 75$	High IEff $I^{LT}_{h,4} = 41$	Low IEff $I^{PT,2}_{l,4} = 548$	High IEff $I^{PT}_{h,4} = 225$
Avg IEff	0.36	0.80	0.46	0.83	0.20	0.96
(Std Dev)	(0.34)	(0.21)	(0.38)	(0.21)	(0.29)	(0.14)
APP	0.12	0.15	0.13	0.05	0.11	0.09
AMB	0.97	0.88	0.13	0.05	0.96	0.92
CV	0.94	0.26	0.83	0.25	1.45	0.15
D^{APP}	0.12		0.19		0.06	
(p-value)	(0.62)		(0.29)		(0.72)	
D^{AMB}	0.19		0.07		0.07	
(p-value)	(0.11)		(1.00)		(0.37)	
Number of firms for clustering	-		-		-	

- Based on the D^{APP} and D^{AMB} statistics presented in the table, monopoly rent-seeking, and innovation ambidextrous firms, no longer differ with respect to these two innovation strategies.

Hierarchy of innovation efficiency groups and innovation strategies (IRP portfolio and innovation ambidexterity)



Conclusions

- The incorporation of innovation strategy orientation substantially increases the discriminatory power of the efficiency measurement.
- Firms with lower levels of innovation efficiency are focused on securing monopoly rents from an augmented IPR portfolio.
- Firms with higher levels of innovation efficiency are more focused in attaining competitive rents from their innovation outputs.
- Competitive rent seeking firms adopt separately or jointly exploitation and exploration innovation strategies only if the trade-offs in terms of innovation efficiency are not significantly high.
- Monopoly rent seeking firms which adopt both exploration and exploitation innovation strategies have lower levels of innovation efficiency.
- Monopoly rent seeking firms which adopt only exploration innovation strategies have higher levels of innovation efficiency.
- The inclusion of innovation strategies, i.e., IPR portfolio and innovation orientation, leads to the formation of latent hierarchically structured and heterogeneous firm groups. The resulting structured hierarchy clearly points to an innovation strategy complexity and innovation efficiency trade-off relationship.

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