How Information Technology Contributes to Justice Efficiency
A Comparison between France and Austria

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Abstract

This paper explores how information technology (IT) contributes to judicial efficiency, that is, to what extent investment in IT helps shorten court delays. It uses information collected by the European Commission for the Efficiency of Justice (CEPEJ), a body of the Council of Europe, from the ministries of justice of 16 of its member countries. A part of this survey, conducted every two years by the CEPEJ, focuses on the judicial services information system, which every country describes by filling up checkboxes. The research augments CEPEJ data by building a maturity index from that material. That index, designed as a proxy to IT asset, is then used as an input to a data envelopment analysis (DEA), alongside two types of human assets : judges and other staff. The average court delays, in criminal and civil matters, are used as outputs to the DEA. One first stage of the analysis applies the directional distance function (DDF), a second one applies the Shapley value, so as to weigh each input's contribution to the distance from the efficient frontier. Results suggest IT does indeed contribute to shorter court delays, but also that other factors are at play. Two countries of the panel, France and Austria, are selected for their highly diverging digitalization paths. A supplementary historical analysis of their respective IT spending and IT policy suggest that regulatory setup and IT project governance may matter just as much as money spent in IT.

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1 Introduction

Many scholars, like Lewin et al. (1982), Kittelsen and Førsund (1992), Peyrache and Zago (2016), Voigt (2016), Gomes et al. (2018), have studied the efficiency factors of the judiciary, mostly at court level, of one single country, and through easily quantifiable variables like numbers of judges or office staff. Some of them, especially Elbialy and García-Rubio (2011), Yeung and Azevedo (2011), Deyneli (2012), Andrade and Joia (2012), Lorenzani and Lucidi (2014), Månsson et al. (2022) ponder to what extent information technology (IT) has an effect on judicial efficiency. Such studies are all the more relevant that some countries see their court delay remain high or rise despite an increased investment in the IT of their judicial services.

The European Commission for the efficiency of justice (CEPEJ) has been collecting, every two years, since 2006, raw data from participating countries, so as to help them assess how efficient they are relative to each other and how they make progress over time. The CEPEJ tracks the "disposition time", that is, the court delay, or average number of days between the filing of a case and its settlement by a judge, which is the most consensual indicator to assess the efficiency of a judiciary. The CEPEJ methodology is based on self-assessment and makes little room to the analysis of information systems. Rather than analyzing the role of legacy systems, it focuses on cutting-edge developments. In 2018, the European Commission (EC) joined forces with the CEPEJ to evaluate different features of each participant's judicial information system. Their common approach does not provide a solution to the problem of quality and comparability of data provided to the CEPEJ by the ministries of justice. Velicogna and Ontanu (2021) warn that outcomes must be received with extreme caution.

The purpose of this paper is twofold. First, assessing the relative contribution of IT, as opposed to that of human assets, to the efficiency of justice. Second, providing some methodological tools to the measurement of judicial efficiency. Like Lewin et al. (1982), Kittelsen and Førsund (1992), Hagstedt and Proos (2008), Yeung and Azevedo (2011), Deyneli (2012), a data envelopment analysis (DEA) model is employed, a model where efficiency comes from maximized output production or minimum input consumption. The directional distance function (DDF) is used, on the steps of Falavigna et al. (2015), Peyrache and Zago (2016) and Månsson et al. (2022). In particular, three methodological innovations are introduced:

- Augmentation of the CEPEJ indicators with a maturity index of the information system of each country's judiciary and use it as a proxy of its IT asset value;
- Choice of the disposition time as the efficiency indicator instead of the number of resolved cases, used by Schneider (2005), Hagstedt and Proos (2008), Falavigna et al. (2015) and Beldowski et al. (2020) or the rate of resolved cases used by Elbialy and García-Rubio (2011) and Deyneli (2012); this avoids any uncontrollable variable in the dataset;
- Application of the Shapley value to assess the contribution of each input, instead of the

Tobit or Farrell decomposition, used by Deyneli (2012) and Månsson et al. (2022) respectively. In order to provide additional robustness, the Equal Surplus (ES) value is also employed to measure the contribution of each input, in particular that of the IT system. The datasets and the python codes for Shapley contributions (as well as DEA and ES) are available (see Appendix 8.1 for code usage).[1]

One limit of DEA is to see (in)efficiency as depending solely on inputs, not on burdens. The IT governance, the regulatory framework applicable to the judiciary, the complexity of law and judicial culture, are not inputs. They may be burdens, that foster inefficiency. In particular, a lack of IT governance may be the source of technical debt, reducing or reversing the contribution of IT to efficiency. To get insights on such factors, this study includes a longitudinal and comparative analysis of two countries with particularly diverging paths. The followed reasoning is that the success factors of one will enable to highlight the failure factors of the other. France and Austria are selected.

The study unfolds in three steps: first, an information system maturity index is built from the CEPEJ data. Second a DEA is applied, where human assets (judges and office staff) and IT assets are both inputs, and average disposition times in civil and criminal matters are outputs. Results given by the DDF are then decomposed into the contributions of each input according to Shapley and ES. The last step is the comparative and qualitative analysis between France and Austria.

The paper is organized as follows. A review of the literature is first proposed to have a look on the methods to measure efficiency, the type of IT variable and the area among other things (Section 2). We then describe the DEA model and how to measure the contribution of judicial IT to justice efficiency (Section 3). A new maturity index is proposed, decomposed into specialized sub-indices (Section 4). The single index and the set of sub-indices are alternatively applied to a dataset of 13 comparable countries (Section 5). From these preliminary results, a focus is put on France and Austria, for further analysis of spending data and IT policy since the inception of their judicial IT (Section 6). Methodological avenues are proposed in the conclusion (Section 7).

2 Literature Review

The efficiency of information systems (IS) is a major matter of research in computer science. Delone and McLean (1992) devised a model as a framework for conceptualizing and operationalizing IS success. Technical debt, an expression initially coined by Cunningham (1992), has been further investigated. Avgeriou et al. (2016) defined it as the result of technical compromises that are expedient in the short term, but that create a technical context that increases complexity and cost in the long term. Rinta-Kahila et al. (2023) say it is often

[1] See our github DEA_Shapley Repository

revealed when the organization aims to replace legacy systems.

Other researchers investigated economics of justice. Botero et al. (2003) pointed at overly complicated procedures as a bigger cause of poor judicial performance than a low level of resources poured into the judicial system. Melcarne et al. (2019) showed that reforms seeking court delay reduction do not necessarily deteriorate quality of justice. Blank and Heezik (2020) applied a cost function approach to analyse the efficiency of the Dutch judiciary over the long period. Beldowski et al. (2020) found that determinants of court performance and efficiency remain poorly understood in general.

Elbialy and García-Rubio (2011) and Yeung and Azevedo (2011) studied, in unrelated works, the effect of the number of computers installed in courts on the efficiency of the Egyptian and Brazilian judicial systems respectively. Lorenzani and Lucidi (2014) found that fostering investment in what they call "in-court" IT positively affects the efficiency of civil justice. Voigt (2016) cited IT as one of the many factors of judicial efficiency. On their part, Palumbo et al. (2013) found a tenuous link between the budget allocated to the computerization of justice and the length of the trial whereas Gomes et al. (2018) concluded that the direction of causality between investment in technology and court productivity was unclear. In Italy, Mazzocchi et al. (2024) investigated the link between the database managing a type of litigation (SICID for civil and labour cases, SIECIC for bankruptcy proceedings) and the resulting average disposition time and found the former is a valid determinant of the latter.

Several works have been based on the DEA (see Section 3 for details). This method, devised by Charnes et al. (1978), measures the efficiency of decision-making units (DMU) based on the interrelation between inputs and outputs. Ruggiero (1996) show it easily applies to service production, including public services, because it is nonparametric and does not require input price data. For instance, Tapia and Salvador (2022) show that scores, such as consumer-satisfaction opinion, can also be used as inputs or outputs, just as any physical quantity.

In the field of justice (court) efficiency, studies have in common to view individual courts as DMU, as per Charnes definition, or aggregate courts at the country level. Lewin et al. (1982) were first to use DEA in the judicial domain. They applied this technique to criminal superior courts of North Carolina and since then others have used it to other specific jurisdictions or countries, see Lopes and Silva (2024). Yeung and Azevedo (2011) found that the lack of computers is not a sole reason of inefficiency. Deyneli (2012) applied a two-stage DEA to CEPEJ data, where countries are the DMUs, number of judges and office staff are inputs and resolved cases are outputs. In the second stage, DEA scores are regressed with variables affecting the courts by the Tobit regression model. He built computerization scores on the basis of the rates of implementation in three application areas (judge assistance, judicial administration, communication with parties) declared by countries participating to

the CEPEJ benchmark of 2008 (on 2006 data). He did not include this computerization index among inputs, but used it as an explanatory variable in the Tobit regression stage. He found no impact of computerization on the number of resolved cases.

Investigating the specific contribution of IT to court performance is challenging. Many countries have left tribunals in charge of IT spending in the early 1980 or 1990s, leading to duplicate software developments, and now tend to centralize IT at national or federal level, at least for its infrastructure layer. If, for a DEA, human resources and operating budget are still valid discretionary inputs for tribunals, the central judicial administration tends to be the most relevant DMU for IT investment. See Table 1 for a more comprehensive inventory of related researches.

Table 1: Related efficiency studies in judicial systems

Authors	**Area**	**Matter of law**	**Model**	**DMU**	**IT as a factor**	**Efficiency indicator**	**Factor attribution**
Lewin et al. (1982)	North Carolina	criminal	DEA	tribunal		resolved & pending cases	
Kittelsen and Førsund (1992)	Norway	all	DEA	tribunal		(multiple)	
Schneider (2005)	Germany	labour	DEA	court of appeal		resolved cases	
Hagstedt and Proos (2008)	Sweden		DEA	tribunal		resolved cases	
Elbialy and García-Rubio (2011)	Egypt	all	DEA	tribunal	number of computers	resolution rate	civil vs criminal
Yeung and Azevedo (2011)	Brazil			tribunal	rate of computers		
Deyneli (2012)	CEPEJ		DEA	country	computerization score	resolution rate	Tobit
Andrade and Joia (2012)	Brazil			tribunal	IT investment		
Palumbo et al. (2013)	35 countries			country	IT budget share	trial length & resolution rate	
Lorenzani and Lucidi (2014)	CEPEJ	civil		country	IT budget share	disposition time & backlog ratio	
Falavigna et al. (2015)	Italy	tax	DDF	tribunal		resolved cases	
Peyrache and Zago (2016)	Italy		DDF	tribunal		resolved cases	per court size
Gomes et al. (2018)	Brazil		least squares	tribunal	build & run IT spending		

Table 1: (continued)

Authors	Area	Matter of law	Model	DMU	IT as a factor	Efficiency indicator	Factor attribution
Beldowski et al. (2020)	Poland	commercial	SFA	tribunal		resolved cases	
Månsson et al. (2022)	Sweden		DDF	tribunal		resolved cases	Farrell decomposition

3 Methodologies

This Section briefly exposes the directional distance function and its estimation by DEA. Then, the Shapley value and the Equal Surplus are described to understand how to compute the contribution of each feature (input) to the DEA score of the DDF.

3.1 Efficiency and DEA

A production technology describes how inputs $x = (x_1, \cdots, x_n) \in \mathbb{R}^n_+$ are transformed into outputs $y = (y_1, \cdots, y_m) \in \mathbb{R}^m_+$. The production possibility set T is the set of all feasible input and output vectors:

$$T = \big\{(x, y) \in \mathbb{R}^{n+m}_+ : x \text{ can produce } y\big\}.$$

It satisfies the following assumptions.

(T1): $(0, 0) \in T$, $(0, y) \in T \Longrightarrow y = 0$ *i.e.*, if there is no judge, IT devices, or other inputs to measure court efficiency, there is no output such as disposition time.

(T2): the set $A(x) = \{(u, y) \in T : u \leqslant x\}$ of dominating observations is bounded $\forall x \in \mathbb{R}^n_+$, *i.e.*, infinite outputs cannot be obtained from a finite input vector.

(T3): T is closed (otherwise the efficiency measure could be infinite).

(T4): $\forall z = (x, y) \in T$, $(x, -y) \leqslant (u, -v) \Longrightarrow (u, v) \in T$, *i.e.*, fewer outputs can always be produced with more inputs, and inversely.

The directional distance function (DDF) introduced by Chambers et al., 1996; Chambers et al., 1998 is completely characterized by assumptions (T1)-(T4).[2] The DDF, denoted as $D_T : \mathbb{R}^{n+m}_+ \times \mathbb{R}^{n+m}_+ \longrightarrow \mathbb{R}_+$ involving a simultaneous input and output variation in the direction of a pre-assigned vector $g = (g_i, g_o) \in \mathbb{R}^{n+m}_+$ is defined as:[3]

$$D_T(x, y; g) = \sup_{\delta} \big\{\delta \in \mathbb{R} : (x - \delta g_i, y + \delta g_o) \in T\big\}.$$

[2]Convexity is sometimes employed, but it is not necessary in some cases, see Ravelojaona (2019).

[3]In the sequel, we do not investigate the cases of infeasibilities for which $D_T(x, y; g) = -\infty$, the directional distance being such that $D_T(x, y; g) \geq 0$, see Briec and Kerstens (2009).

The DDF is a measure of inefficiency related to a given technology T. This measure is commonly called technical efficiency. It gauges how much input contraction and output expansion are necessary for a decision making units (aggregate courts for instance at level country) to be on the frontier, *i.e.* to be efficient.

As Peyrache (2013) pointed out, the directional distance function can be interpreted in terms of units of input waste (such as the number of judges) and units of output loss (time loss). Some limitations of the DDF could arise if the convexity assumption of the technology is invoked[4]. In this case the technology cannot capture some properties of complementarity or susbstitutability between inputs and/or outputs, see Briec and Mussard (2020) for solutions related to cooperative game theory.

DEA allows to infer directly from the data the relative efficiency of each decision making unit. For instance, Falavigna et al. (2015) show the benefit (and the limits in case of externality) of DEA while assessing judicial efficiency of Italian tax courts. Also, Peyrache and Zago (2016) develop an approach to attribute court inefficiency to different determinants (technical, size and reallocation inefficiency) of the Italian justice sector. With a linear programming, the DDF can be estimated by DEA as follows:

$$\begin{aligned} D_T(x,y;g) = \max\ & \delta \\ \text{s.t. } & x_i - \delta g_i \geq \sum_k \theta_k x_{ik},\ \forall i = 1,\cdots,n \\ & y_j + \delta g_o \leq \sum_k \theta_k y_{jk},\ \forall j = 1,\cdots,m \\ & \delta, \theta_k \geq 0. \end{aligned}$$

The advantage of the DDF relies on the choice of the direction. If $g = (g_i, 0)$, the DDF is input oriented. In this case the efficiency is related to the ability of the decision making unit to manage and reduce its inputs. On the other hand, if $g = (0, g_o)$, the DDF is output oriented. In this case, the DDF measures how the decision making unit is able to improve its outputs without having the possibility to reduce its inputs. Peyrache and Zago (2016) chose to run an output-oriented analysis because the Italian judiciary is already low in resources: it has no room to reduce its humans assets. This assumption is valid in this context, because there is one single HR policy at country level so the constraint applies to every tribunal. In a context where the DMU is a country, no assumption can be made as to whether efficiency gains are best reached by minimizing inputs or maximizing outputs at aggregate level. In the sequel, the direction is therefore set to $g = (\mathbf{1}, \mathbf{1})$.

The linear programming can be adapted to a technology satisfying one of the following

[4]In this case, the DDF is concave, see Briec, Dervaux, et al. (2003)

assumption about returns to scale. The constraint $\theta_k \geq 0$ imposes a constant returns to scale assumption (CRS), however other assumptions may be imposed on linear programming:

- $\sum_k \theta_k = 1$ (Banker et al., 1984) allows a variable returns to scale assumption (VRS).
- $\sum_k \theta_k \leq 1$ (Seiford and Thrall, 1990) allows a decreasing returns to scale assumption (DRS), which is strictly speaking a non increasing returns to scale assumption).
- $\sum_k \theta_k \geq 1$ (Grosskopf, 1986) allows an increasing returns to scale assumption (IRS), which is a non decreasing returns to scale assumption.

These constraints will be discussed in the empirical Section 5.

3.2 Contribution of each input: Shapley and ES

In a second step, our aim is to measure the contribution of each factor (input) to justice (in)efficiency. This allows to understand the source of inefficiency and to discuss whether IT factors have more or less influence.

Let $\mathcal{N} := \{1, 2, \cdots, n\}$ be the set of inputs and $\mathcal{S} \subseteq \mathcal{N}$ be a coalition of inputs x_k of size $|\mathcal{S}|$. Let v be the characteristic function of the game such that $v(\mathcal{S})$ yields the DEA score of the DDF measured on the input coalition $\mathcal{S}$. The marginal contribution of input x_k to the DEA score produced with coalition $\mathcal{S}$ is denoted $v(\mathcal{S} \cup \{k\}) - v(\mathcal{S})$. Averaging the marginal contributions of input x_k with all coalitions $\mathcal{S}$ provides the celebrated Shapley value (Shapley, 1953):

$$\varphi_k^{Sh}(v) := \sum_{\mathcal{S} \subseteq \mathcal{N} \setminus \{k\}} \frac{(n - |\mathcal{S}| - 1)!|\mathcal{S}|!}{n!} \Big(v(\mathcal{S} \cup \{k\}) - v(\mathcal{S}) \Big), \ \forall k \in \mathcal{N}$$

with $v(\emptyset) := 0$. The Shapley value has been employed in many fields such as finance to compute the contribution of assets (Mussard and Terraza, 2007), the contribution of features being pixels in images, words in documents (Condevaux et al., 2022), or any given qualitative or quantitative information. The contribution φ_k^{Sh} may be negative. In this case when input x_k is added to a coalition of inputs $\mathcal{S}$ it decreases the DEA score *i.e.* it decreases inefficiency. Consequently, input x_k is considered as an important feature explaining the DEA score.

In the literature, the Equal Surplus (ES) value has been shown to be relevant for text and image classifications, see Condevaux et al. (2022). It is given by:

$$\varphi_k^{ES}(v) := v(\{k\}) + \frac{v(\mathcal{N}) - \sum_{k=1}^n v(\{k\})}{n}, \forall k \in \mathcal{N}. \tag{3.1}$$

The ES value provides the contribution of input x_k alone (that is $v(\{k\})$) plus the contribution of all inputs equally shared between them (that is $(v(\mathcal{N}) - \sum_{k=1}^n v(\{k\}))/n$). Remark that $v(\mathcal{N}) - \sum_{k=1}^n v(\{k\})$ is the efficiency produced by all inputs in excess of the sum of all individual efficiencies. This difference must be negative when all inputs together tend to

provide an efficient score (close to 0). Therefore φ_k^{ES} may be negative, in this case the input x_k decreases inefficiency and as such can be considered as an important feature.

Shapley and ES capture two different methods to measure the contribution of each input to the global DEA score. While the former considers all possible marginal contributions, the latter focuses on the individual role of each input. In the Shapley case, if one input x_k is null in the sense that it cannot produce any given marginal contributions ($v(\mathcal{S} \cup \{k\}) = v(\mathcal{S})$ for all $\mathcal{S} \in \mathcal{N} \setminus \{k\}$), then its final contribution is null. On the contrary, the ES value can produce non-null contributions even if the individual efficiency score is null ($v(\{k\}) = 0$). The employ of two techniques, Shapley and ES, enables more robustness to be captured about the selection of the important input contributions.

4 An augmented CEPEJ dataset

A team of OECD (OECD, 2013, p. 92) considers that neither the centralized or federal character of a country, nor its size in terms of population, are determining factors in central government IT spending. It is therefore possible to use the list of sixteen countries qualified by the CEPEJ (2010) as comparable in terms of development level, whatever their size and mode of government, and make use of raw data provided by each country for that survey.

A first subsection is devoted to the construction of a maturity index, then a second subsection presents the data to measure efficiency.

4.1 Building an information system maturity index

Data declared to the CEPEJ by participating countries are shaky (for instance, France and Austria declare almost the same IT spending amount for 2010 despite the country size difference). Moreover CEPEJ budget data cover only the period since 2006. The CEPEJ does not collect the numbers of computers, and inefficiencies persist today even though most judiciaries have nearly completed the equipment of their front-office users. [5]

An information maturity index is built as a proxy of IT spending. There is a difference, though: the index reflects the value of assets, not the cumulative spending which, if higher, would reveal waste. We start from the CEPEJ (2020a) evaluation cycle covering data from 2018. Thirteen sections relate to the evaluation of the judicial information system, more fine-grained than the three ones available to Deyneli (2012) for 2006 data.

[5] We suspect most issues lie at the back end of applications and do not regret a variable that has lost its explanatory power.

Table 2: Judicial System Features and Scores by Country*

Feature	**Type**	**(*)**	**Ref.**	**AT**	**BE**	**CH**	**DE**	**DK**	**ES**	**FI**	**FR**	**GB**	**GR**	**IT**	**NL**	**NO**	**PL**	**PT**	**SE**
Caselaw database (civil + criminal, 1st + 2nd degree)	1	C	62-4-1	2	2	3	2	0	3	1	1	0	0	0	2	3	2	1	2
Information through intranet	1	C	62-9.1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1
Writing support, dictaphone & speech recognition	2	E	Table 6.1	2.8	0.8	0	2.3	2.3	2.3	2	0.4	1	0.8	1.5	0	1	1.9	2	2
Case management	2	E	Table 6.2	6.4	5.3	3	3.3	5.1	4.9	5.6	4.8	4	3.9	6.1	4.5	6.5	6.3	6.2	5.1
Budget & judicial fees management	2	E	Table 6.3	0	1.5	1.5	1.3	0.4	1	1	2	1.75	1	1.8	0.5	2	2	1.5	0.5
Filing & summmons	2	E	Table 6.5	7	2.3	2.75	7	3.6	7	7	3.3	2	4.5	5.9	0	4	3.2	7	6.3
Judicial aid management	2	E	Table 6.7	4	4	3.75	4	1.5	3	4	1.5	3.75	0	4	2	2.75	0	0	0
Interoperability of criminal records	3	C	62-6	3	3	0	3	0	2	2	3	2	0	3	1	1	3	3	1
Communication with attorneys	3	E	Table 6.6	6	4.35	4.5	6	5.17	6	6	4.64	4	3.78	5.26	1.42	4.5	2.96	5.8	6
Communication with other professionals	3	E	Table 6.8	3	2.3	2.25	3	3	2	2	0.8	0.75	0	2	0	0	1.5	2	2
Communication with police forces	3	C	64-7	1	1	0.75	1	1	1	1	0	0.75	0	0.5	0	0	0.5	1	1
Workload measurement tool	4	E	Table 6.4	4	0.8	3.5	2.5	2.4	4	3.7	1.7	1.66	1.3	3.3	0	3.83	3.5	3.3	4.7
Project management mainly by IT department	4	C	65-2	1	1	1	1	1	1	0	0	1	1	0	1	1	0	1	1
Score				**41.2**	**29.35**	**26**	**37.4**	**26.47**	**38.2**	**36.3**	**24.14**	**23.66**	**16.28**	**34.36**	**13.42**	**30.58**	**26.86**	**34.8**	**32.6**
2018 ranking				**1**	**9**	**12**	**3**	**11**	**2**	**4**	**13**	**14**	**15**	**6**	**16**	**8**	**10**	**5**	**7**

* C stands for: CEPEJ, Profils pays, Exercice d'évaluation, Partie 1, édition 2020 (données 2018)

* E stands for: EC, Study on the functioning of judicial systems in the EU Member States : facts and figures from the CEPEJ questionnaires 2012 to 2020. Part 1, 2022.

Austria comes out first and the Netherlands come out last. The latter case is puzzling, because the Netherlands may have spent substantial sums in its ICT over time : Hoogen et al. (2003) reckon that represented 8 % of the justice budget in 2001. This suggests either wasted money or ill-reported information.

The European Commission's Directorate-General for Justice and Consumers then transformed the collected information into quantifiable data in 2022 for comparison purposes. Its methodology is replicated to the 3 non-EU countries of England/Wales, Norway and Switzerland, see European Commission (2022, Annex 5). The provided raw values are not questioned, for example we disagree with the score of 1 for France on the question of a centralized and interoperable base for civil case management, but accept the resulting total points of 4.8 computed by the EC in the 4th line of our Table 2. A ranking is obtained by adding up together points across all variables.

This maturity index can be broken down by IT feature, into several sub-indices (Type 1 to 4), as shown in Table 3.

Table 3: Maturity of judicial services information systems in 16 comparable European countries - Summary

Type	**1**	**2**	**3**	**4**	
Features	**Information tools**	**Productivity tools**	**Communication tools**	**IT project governance**	**Total**
Austria (AT)	3	20.2	13	5	41.2
Belgium (BE)	3	13.9	10.65	1.8	29.35
Switzerland (CH)	3	11	7.5	4.5	26
Germany (DE)	3	17.9	13	3.5	37.4
Denmark (DK)	1	12.9	9.17	3.4	26.47
Spain (ES)	4	18.2	11	5	38.2
Finland (FI)	2	19.6	11	3.7	36.3
France (FR)	2	12	8.44	1.7	24.14
England/Wales (GB)	1	12.5	7.5	2.66	23.66
Greece (GR)	0	10.2	3.78	2.3	16.28
Italy (IT)	1	19.3	10.76	3.3	34.36
Netherlands (NL)	3	7	2.42	1	13.42
Norway (NO)	4	16.25	5.5	4.83	30.58
Poland (PL)	2	13.4	7.96	3.5	26.86
Portugal (PT)	2	16.7	11.8	4.3	34.8
Sweden (SE)	3	13.9	10	5.7	32.6
cap	5	23	13	6	47

Scores should be welcomed with as much caution as input data. It is striking, for instance, that the Netherlands get only 7 points, against Austria with 20.2, on the productivity tools maturity index, while achieving even shorter disposition times (110 and 104 days for civil

and penal cases respectively, against 138 and 120 for Austria, see Table 4). Should these figures be deemed accurate, they suggest Austria spends far too much in its IT.

These information system maturity indices have their own limitations. They do not provide with a comprehensive representation of the judicial information system. The underlying CEPEJ questionnaire does not include key questions like: What are the shares of IT investment spending committed by jurisdictions and by the ministry? What is the level of database and software technical integration, in particular, to what extent do application systems rely on master data such as personal identification numbers?

4.2 Building the dataset to compute efficiency

This does not yet say to what extent the maturity of the information system, among other factors, contributes to the efficiency of justice, particularly in terms of case processing time. A DDF based on CEPEJ data for 2018 is therefore carried out, in which three inputs and two outputs are employed.

In principle, incoming cases can be regarded as input and settled cases as output, but courts have no agency on the number of incoming cases, which reflects national law and cultural patterns. Moreover, definitions of cases vary across countries. However the average case processing time, which ECHR calls the "disposition time", expressed in number of days, is an adequate metric of judicial production. Our choice of inputs and outputs is therefore as follows:

The inputs are the number of judges per million inhabitants, the number of non-judge justice personnel, again per million inhabitants, and the maturity index of the information system. The two types of populations are separated, because judges are those who settle court cases and need information tools most while other personnel, which are defined as non-judges, have a more intensive use of the information system and are more impacted by productivity tools. The number of consular (non-professional) judges and the number of new cases are note included, these are variables that the ministry does not control.

The outputs are the disposition times as per the CEPEJ definition. These are the average numbers of days, between the date when a case is filed to a tribunal and the date when it is settled by a judge. There is one metric for civil matters and another for criminal matters.

In a DEA-type analysis, production must increase with the increase in inputs. As disposition times are supposed to be reduced with an increase in these three types of inputs, the theoretical output is then defined as a time gained, by subtracting the disposition time to 1000 days (subtracting the disposition time from 10,000 days, an even less attainable maximum, brings similar results).

Accordingly, efficiency is measured by the relationship between the first three variables

(inputs) on the last two (outputs), see Table 4. As some data are missing for Belgium, England/Wales (GB) and Greece, these countries are excluded from the calculation.

The DDF is computed on three different sets of inputs:

- **Input set 1**: judges and non-judges ;
- **Input set 2**: judges, non-judges and our single maturity index ;
- **Input set 3**: judges, non-judges and the four maturity sub-indices, shown in Table 3. As variables are not weighted, parallel computations on the three input sets allows to look at gaps and check the solidity of our model.
- **Output**: There is one single output set for the three input sets. It is composed of two variables:

$1,000 -$ disposition time of civil matters;

$1,000 -$ disposition time of criminal matters.

While other authors, such as Peyrache and Zago (2016), focused on the number of settled cases, we instead employ average disposition times. By working with averages, we neutralize concerns about how the mix of judicial activities between criminal and civil matters might vary across the countries in our panel.

5 DEA and input contributions

We present the results of the DEA scores, followed by an analysis of the contributions of inputs using Shapley and ES methods.

5.1 DEA scores

Input sets 1 and 2 allow to show by difference the possible contribution of IT to a multi-output production efficiency.

Sets 2 and 3 are meant to find out what level of detail of representation of IT best suggests causality to disposition times. Table 5 shows the respective efficiency of the 3 input sets to produce the same output set (average of civil and criminal disposition times).

The DEA makes it possible to assess the efficiency of countries relatively with each other at a given time. That the IT factor can move some countries away from the efficient frontier does not mean that IT does not contribute to the shortening of disposition times in absolute terms. Moreover, a strict return to paper in each process - theoretical hypothesis - would mechanically increase the time taken to settle cases.

Table 4: Inputs and outputs of judicial efficiency

Data	**input**	**input**	**input**	**output**	**output**
Variables	1	2	3	4	5
AT	273.3	562.9	41.2	138	120
BE	133.2	435.1	29.35		188 (6)
CH	143.3	596.9	26	111	100
DE	244.8	651.3	37.4	220	117
DK	64.6	285.2	26.47	207	41
ES	115.3	1013.6	38.2	361	170
FI	195.8	385.9	36.3	273	139
FR	108.6	341.0	24.14	420	399 (6)
GB	30.9	240.1	23.66		75
GR	267.6	389.1	16.28	559	
IT	116.2	371.1	34.36	527	361
NL	145.9	433.5	13.42	110	104
NO	102.8	159.7	24.08	176	70
PL	254.5	1058.6	26.86	273	111
PT	192.6	566.1	34.8	229	205
SE	119.0	509.1	32.6	166	151

[1] Judges per million inhabitants, CEPEJ, Country profiles, Evaluation cycle, Part. 1, 2020 edition (2018 data), question 046 / question 001.
[2] Non-judges per million inhabitants, *ibid.*, question 052 / question 001.
[3] Single judicial services information system maturity index.
[4] Disposition time for contentious civil, commercial and administrative cases, CEPEJ, Systèmes judiciaires européens. Rapport d'évaluation de la CEPEJ (données 2018), Partie 1, 2020, p. 115.
[5] Disposition time for criminal cases, *ibid.*, p. 128.
[6] 2020 data.
Empty cell means data was not supplied by the country.

A principle of law holds that a minimum delay is necessary to ensure quality of judicial decisions. The disposition time of any case is constrained by legal provisions related to civil or criminal proceedings. There is therefore a point at which any additional euro invested in the smartest judicial information system will cause no additional shortening of the disposition time. For this reason, DEA scores are computed with *decreasing returns to scale*[6].

Table 5 suggests that IT does contribute to efficiency to the extent every country sees its gap to the efficient frontier reduced when the IT maturity index is included among inputs. The effect is even greater when IT is represented through four proxy variables instead of one, though this does not outline, at this stage, the contribution of IT in the efficiency gain.

Switzerland, Denmark, the Netherlands and Norway have a distance to the efficient fron-

[6]Results from other types of returns are available in appendix, in Table 8 for a single information system maturity index and Table 9 for sub-indices.

Table 5: Technical efficiency – DDF and DRS - Distances

	Input set 1	**Input set 2**	**Input set 3**
judges/million inhabitants	✓	✓	✓
non-judges/million inhabitants	✓	✓	✓
single information system maturity index		✓	
information tools maturity index			✓
productivity tools maturity index			✓
communication tools maturity index			✓
IT project governance maturity index			✓
Austria	22.177	21.614	1.287e-11
Switzerland	7.410e-10	6.547e-12	6.753e-11
Germany	51.864	22.096	2.008
Denmark	2.733e-10	6.551e-12	8.627-12
Spain	55.634	19.799	3.472
Finland	85.298	19.669	1.361
France	56.822	14.997	0.072
Italy	68.567	22.585	3.330
Netherlands	2.453e-09	5.957e-12	9.374e-12
Norway	3.040e-10	6.988e-12	9.790e-12
Poland	68.851	12.335	1.695
Portugal	80.423	22.555	1.527
Sweden	11.615	11.233	1.704

tier very close to zero. IT does not make a visible difference to their efficiency. In the Netherlands, the apparent lack of maturity of the judicial information system does not prevent tribunals to deliver short disposition times: on the face of it, the efficiency of the Dutch judiciary derives from a small IT resource. But efficiency does not capture the eventual waste factor. For other countries, IT does reduce their distance to the efficient frontier.

Keeping in mind each country's efficiency is computed relatively to every other countries, ranking them as per their distance to the efficient frontier, see Table 6, brings further elements.

Between input set 1 and input set 3, Germany loses 4 places in the ranking, Spain and Sweden lose 5. Conversely, Finland gains 6 places and Portugal 4. This may be because the first three did not reduce their human assets while the increase of their IT assets should have permitted them to. France gains 3 places, suggesting its IT investment effort has the right mix and enabled it to partly offset a lack of human assets. Relative to input set 2, the disaggregation of the maturity index (input set 3) does not change the ranking very much, except for four countries.

Caution is advised. Tables 2 and 3 are not enough to explain efficiency gaps. Outgoing

Table 6: Technical efficiency - DDF and DRS - Country ranking

	Input set 1	**Input set 2**	**Input set 3**
Austria	6	10	4
Switzerland	3	2	5
Germany	7	11	11
Denmark	1	3	1
Spain	8	9	13
Finland	13	8	7
France	9	7	6
Italy	10	13	12
Netherlands	4	1	2
Norway	2	4	3
Poland	11	6	9
Portugal	12	12	8
Sweden	5	5	10

rankings do not capture the time taken for the IT investment to mature and have the expected effects on efficiency, an issue already raised by Andrade and Joia (2012). Additionally, going from input set 1 to input set 2 (or 3) does not capture all possible effects of IT on efficiency. IT must be combined with all input combinations, as in Shapley and ES, to bring out the full effect of IT on efficiency.

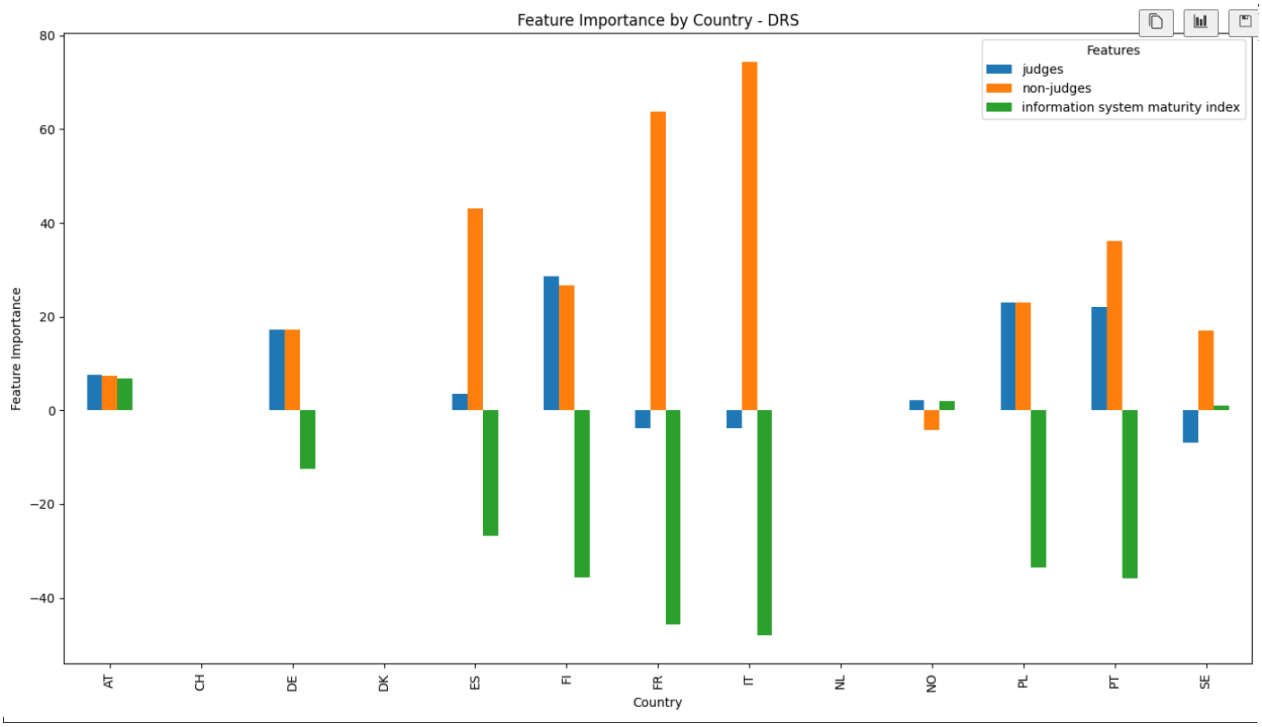
5.2 Input contributions: discussion

In most countries, IT investment does offset human resources related inefficiencies (downward green bars in Figure 1). However, in Austria, Norway and Sweden, IT investment also adds distance to the efficient frontier, probably to the extent disposition times are already satisfactory, suggesting that these countries consume IT somewhat in excess for that outcome. Sweden is unique in that its number of judges improves efficiency. Unlike Austria and Norway, its number of judges per million inhabitants is below average. Combined with a good maturity score, this suggests that the country has been able to leverage its IT investment to keep the number of judges low.

France and Italy show a similar pattern: their proportion of judges is slightly beneficial, but that of non-judges strongly detrimental, to efficiency. IT spending partly offsets an overall human inefficiency.

Switzerland, Denmark and the Netherlands show no input factor at all. They are at their optimum. This is odd for Switzerland where the judicial information system is managed at canton level, and is therefore highly fragmented. The need arose to devise a countrywide system called Justitia 4.0, currently under development, suggesting the actual IT assets do

Figure 1: Input contribution to the DDF: Single index, DRS, Shapley

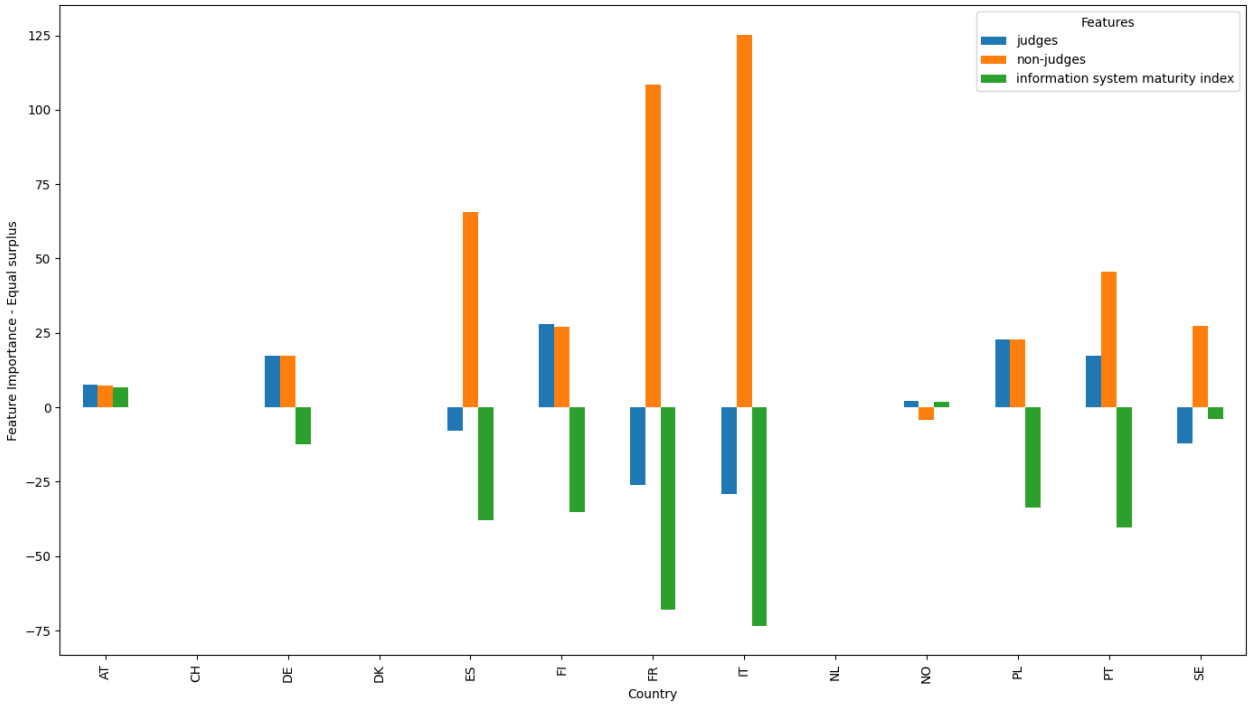


not contribute that much to judicial efficiency after all.

Norway is the only country whose relative number of non-judges positively contributes to efficiency. This number is also the lowest, by far, in the panel. Though we do not know how Norway can consume so few resources (simple procedure? short legal delays?), this does explain why this variable contributes positively to Norway's efficiency, and negatively to the others.

Results of the Equal Surplus method are displayed in Figure 2. The method finds a more positive contribution of judges to efficiency, particularly for Spain. Overall, such results are consistent with the Shapley value and suggest the methodology applied is robust.

Figure 2: Input contribution to the DDF: Single index, DRS, Equal surplus



Splitting the information system maturity index in 4 sub-indices provides some insights, see Figures 3 and 4. Where (in Spain, France and Italy) the number of judges reduces inefficiency in the presence of one single index, it participates to it with the four alternate ones.

Austria seems to be an exception: productivity and communication tools participate to inefficiency while information tools and IT project governance participate to its efficiency. This suggests Austria spends more than is necessary on those two axes. The 4 factors behave in parallel and positively to efficiency for other countries, except Norway. This suggests the spending mix in IT is quite similar between countries. It is unclear why information tools and project governance appear to carry more weight than the other two axes, particularly productivity tools, which account for nearly half of the cap score (23 out of 47 points, as shown in the last line of Table 3).

Figure 3: Input contribution to the DDF: Sub-indices, DRS, Shapley

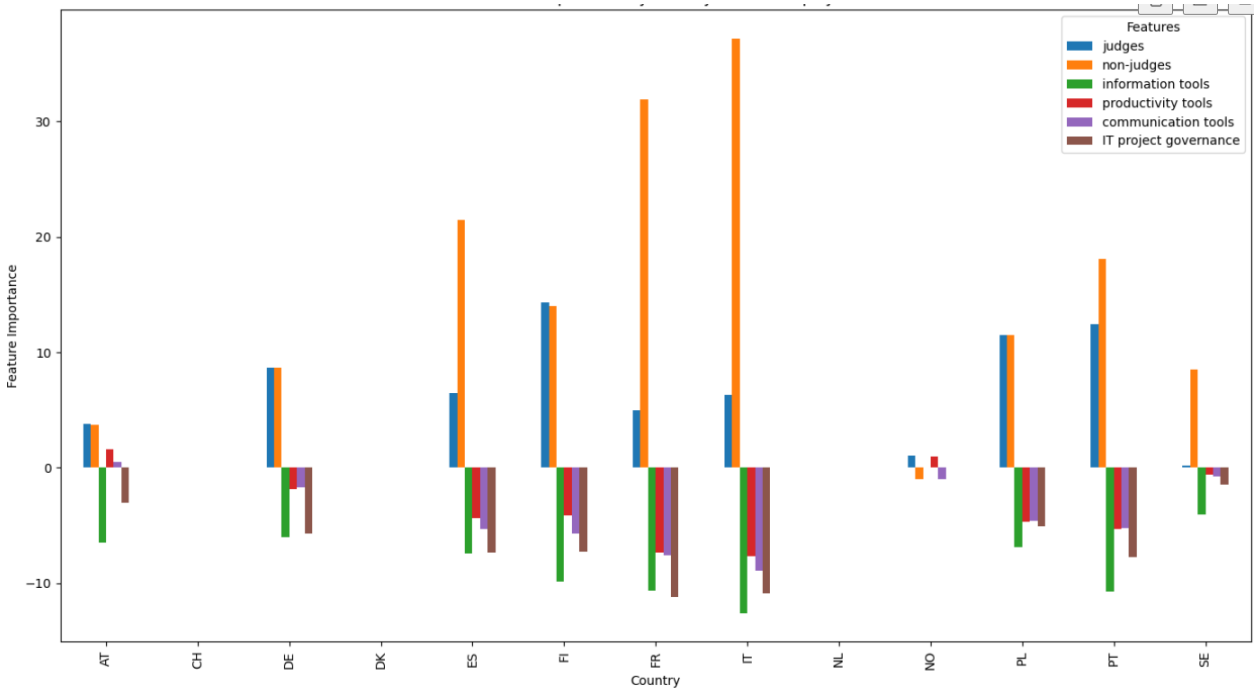
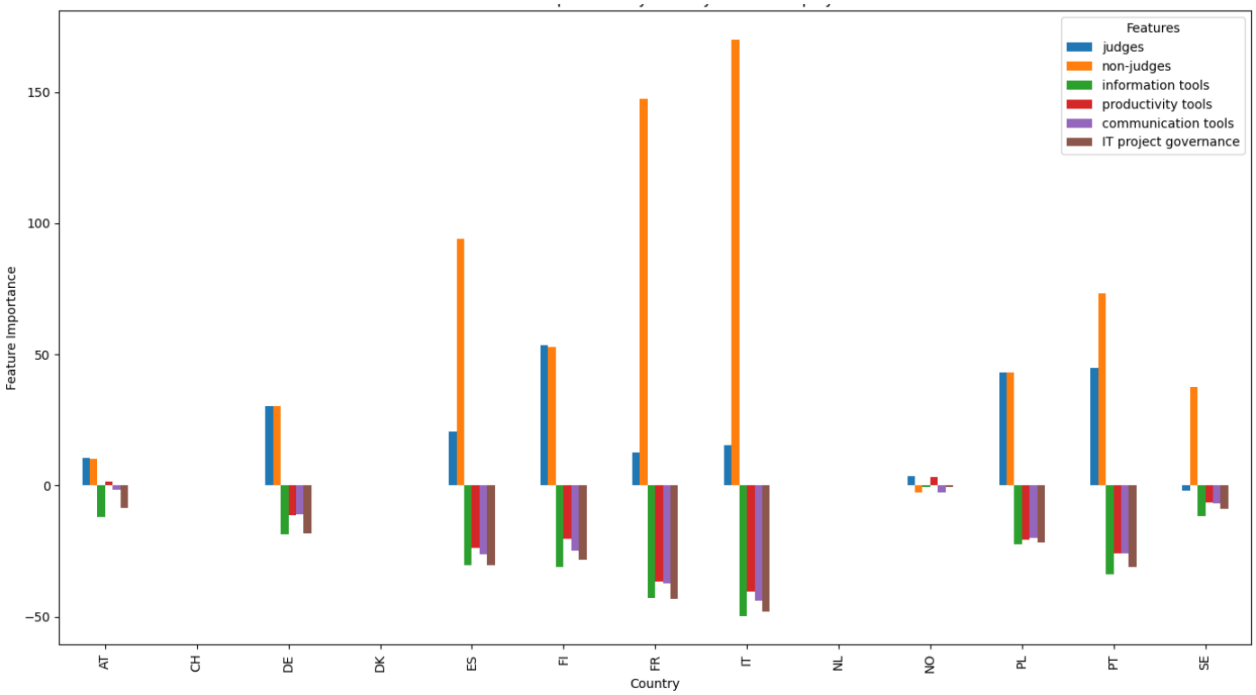


Figure 4: Input contribution to the DDF: Sub-indices, DRS, Equal surplus



Due to a lack of data, the same DEA cannot be applied at an earlier date, therefore no productivity indicators can be derived. However, other variables can be analyzed over time such as the number of contentious decisions and judicial services staff from the 'country profiles' established by the CEPEJ. On this basis, variations can be measured between 2004 and 2018. The use of computers being more intense among clerks, a distinction can be made between the number of civil and criminal decisions by judge and another by "non-judge", the numbers of clerks, among non-judges, not being further isolated in the questionnaires submitted to the participants.

Table 7: Number of decisions[1] by judge and non-judge

		2004		2018		variation	
Country	**Code**	**judge**	**non-judge**	**judge**	**non-judge**	**judge**	**non-judge**
Austria	AT	56,5	20,5	91,0	44,2	60,9 %	115,9 %
Switzerland[3]	CH	418,6[2]	124,6[2]	259,8	62,4	-37,9 %	−49,9 %
Germany	DE	46,8	11,9	154,7	58,2	230,6 %	387,4 %
Denmark	DK	701,1	181,4	548,3	124,2	-21,8 %	−31,6 %
Spain	ES	121,8	17,4	374,4	42,6	207,4 %	145,2 %
Finland	FI	111,4	37,7	85,1	43,2	-23,6 %	14,6 %
France	FR	412,9	155,7	360,1	114,7	-12,8 %	−26,3 %
Italy	IT	391,9	83,0	417,1	130,6	6,4 %	57,3 %
Netherlands[3]	NL	590,3	226,8	585,5	197,1	-0,8 %	−13,1 %
Norway	NO	60,5	31,5	72,0	46,4	19,2 %	47,2 %
Poland	PL	189,3	54,6	216,3	52,0	14,3 %	−4,7 %
Portugal	PT	356,0	83,2	217,4	74,0	-38,9 %	−11,1 %
Sweden	SE	418,6[2]	124,6[2]	261,0	61,0	36,7 %	−18,2 %

[1] contentious civil and commercial, administrative and criminal decisions rendered at first instance
[2] figure of 2006
[3] including non-contentious civil decisions
Source: CEPEJ

The variations computed in Table 7 reflect productivity as well as the effects of law reforms or specific events in each country. For instance, Germany experienced a sharp increase in asylum-law-related decisions between the two dates.

6 Comparison between France and Austria

A DEA based on CEPEJ data having its limits, this Section 6 is devoted to supplement it with a zoom on two countries having markedly different digital transformation paths, so that the success factors of one may, by contrast, highlight the failure factors of the other. This Section 6 first explains why Austria is selected as an example and France as a counter-example. It

then zooms on their respective IT spending, and their respective IT policies.

6.1 Choice of countries

Austria has the best information system maturity index (Table 2). Its average delay in contentious civil and commercial cases is relatively low and stable : 135 days in 2006 (CEPEJ, 2008, p. 154), 138 in 2018 (Table 4). The contribution analysis suggests Austria may have invested in IT somewhat more than necessary (Figure 1). The productivity of judges rises by 60,9 % and that of non-judges by 115.9 % over that period (Table 7). The success of its platform connecting with lawyers earns the country the European Union's e-government label in 2001. BCG et al. (2022) cites Austria among four countries that they consider particularly advanced, alongside the United Kingdom, Canada and Singapore, in terms of digital justice.

France ranks 13th out of 16 countries in terms of information system maturity (Table 2). Its average court delay in civil matters rises from 262 in 2006 to 420 in 2018. France witnesses a 12.8 % drop of productivity of judges between 2004 and 2018, and 26.3 % for non-judges (Table 7) in a period of increasing obsolescence of the main case management applications. The country is also known for its historically mediocre level of funding of the justice ministry, see Asselain (2009). Chantal Arens, former first President of Court of Cassation, hints this affects investment in IT as well, see Vignal (2022). The ministry admits it suffers from a technical debt. Whether the past or current level of IT spending is enough to explain why French justice is late in its digital transformation has not been investigated.

6.2 IT spending

The comparison is difficult because figures published by the two countries do not have the same scope. The Austrian Ministry of Justice manages the broadcasting of legal and case law information (RIS system), and administers the land register (*Grundbuch*) and the trade and companies register (*Firmenbuch*). In France, these functions are carried out respectively by the services of the Prime Minister (*Légifrance*), the Ministry of the Interior and the Ministry of Finance; conversely, the criminal record (*Strafregister*), managed in France by the Ministry of Justice, is managed in Austria by the Ministry of the Interior. On the other hand, in France, commercial justice IT is handled by commercial court clerks, with separate funding, while the jurisdictions-lawyers network (RPVA) is financed by lawyers. The portion of expenditure intended for the prison administration and the judicial protection of young people, however, does not need to be restated.

The methodology applied is described in Appendix 8.4. France has been spending 5.981 billion euros cumulatively on its IT until the end of 2023, and Austria 1.731 billion on a

comparable basis, see Figure 5. Since the two countries do not have the same size, the expenditure per capita is also analyzed. The French taxpayer cumulatively paid 97.2 euros and the Austrian 154.3 euros, or 58.8 % more on a comparable basis[7]. The second graph, in Figure 6, shows that the relative budgetary effort of Austria compared to France is clear, particularly between 2000 and 2006. The gap has narrowed from 2012, and since 2021, the average French person spends more than the Austrian.

Cumulative Austrian spending on judicial IT represents 29% of French spending, while the Austrian population represents 13 to 14% of the French population. One reason of this gap is that, being all paid at market prices under private-law contracts, Austrian software programmers cost more than the French ones. Another reason could be Austrian over-investment or French under-investment.

Our preliminary data envelopment analysis suggests the first assumption is more likely. However, the DEA model does not distinguish investment from operating expenses and best-performing countries from the dataset are not necessarily at their optimum. Indeed, in most countries, the IT budget for justice remains low, relative to the size of the organization. In 1990, in France, it represented only 1.38% of the entire budget of the Ministry of Justice, compared to 2.3% in other ministries. In 2023, IT represents 3.4% of the general budget for justice (2.8% in Austria). For comparison, according to a 2013 survey, the ratio of the IT budget to turnover varies in the private sector between 1% for construction and distribution, to 4% for consulting, services and IT and 9% for financial services, see Mehdi (2013). According to another global study from 2021, professional services devote 13% of their turnover to IT, see Rosé (2023). Similar to an intellectual service activity, justice (judicial services) still has significant room to increase its IT expenditure ratio. Austria is rather closest to the appropriate level of investment among countries averagely suffering from under-investment.

6.3 IT policy

Austria is a federal state, but the organization and judicial procedure are unified as in France. It is the first European country to begin computerizing its criminal record in 1964. This project is placed under the responsibility of the Vienna State Police Directorate, within an information system called EKIS, which also manages the functions of the criminal police. The criminal record system is rolled out in October 1968, see BKA (1972, p. 56). The chancellery decides the Justice Department will have no dedicated IT staff.

[7]To be more precise, in Austria the cost is borne more by the litigant than by the taxpayer. The Austrian judicial system is the most self-financed in Europe, accounting for 70 to 80 % of its budget, in particular from revenues from the fees for land and company registers. To the extent that the government supplements the justice budget, it is unlikely that this specificity explains the share, larger than in France, devoted to IT.

By asking each ministry to set up its own "*Commission de l'informatique*", in 1967, the French government implicitly leaves them by their own devices with IT. From 1971, the *Commission de l'informatique* of the ministry of justice is composed only with magistrates. Its first key decision, in 1972, is to choose the most powerful machine available from CII, a French hardware maker, in a political context where public administrations are expected, through their procurement, to support the development of a national computer industry.

A press article entitled "Safari or the hunt for the French" from Boucher (1974) suggests (wrongly) that this project of a general-purpose identifier for each natural person aims to collect as much information as possible on each citizen. The SAFARI project, on which the ministry was counting, is cancelled. CNIL, the French data protection authority, is born in 1978, in the aftermath of that public row. Unlike its Austrian counterpart, set up the same year, CNIL is mandated with a power to advise public administration on each information system project involving personal data - almost all of them as far as the ministry of justice is concerned. The French ministry of justice's posture is to always follow CNIL recommendations. As the criminal records and the criminal case management solutions devised by the ministry are delayed, jurisdictions gain the right to go it alone in any other of these two areas. The French criminal records reaches cruising speed in 1984, fourteen years after that of Austria.

The Austrian Ministry of Justice opts for centralisation and discourages local initiative. It networks courts and tribunals with the central administration. The ministry starts the dematerialization process of judicial procedures in 1989 and, from then on, makes a significant investment effort. An electronic communication platform (*Elektronischer Rechtsverkehr* or ERV), using proprietary technology, is first applied to judicial payment orders. Austrian lawyers are the first in the world to be able to communicate electronically with their courts. The "Re-design" project is launched in 1997. It overhauls the civil chain and adds a criminal chain, including prosecution service related functionalities, in a single platform. The same year, a law sets up a federal computing centre (*Bundesrechenzentrum* or BRZ). It is the transformation of the chancellery's computing service into a limited liability company owned by the federal state. It pools ministerial resources, and its status allows it to apply a more flexible salary system.

Since 1972 the *Commission de l'informatique* has been working out four-year master plans but the third and the fourth ones are both cancelled before their term. Costs have particularly been spiralling until the second cancellation, in 1992, triggering budget cuts in IT up until 1997. Subsequent master plans are more cautious, but are still more driven by the search for consensus among stakeholders than by that of efficiency.

By contrast, Austrian executives keep themselves from having a grand plan and apply a

no-nonsense approach. They tend to align law to business requirements while the French do the opposite.

In France, CNIL (2003, p. 77) recommends to avoid multiplying interconnections between public administration's information systems. This induces the Ministry of Justice to modernize its information system by building ever larger applications rather than developing a communication infrastructure enabling data to flow between existing ones. A new criminal case management, Cassiopée, is launched in 2003, a civil one, Portalis, in 2012. But rolling out such complex applications nationwide spans over two decades.

In the absence of an electronic communication solution from the ministry, the representative bodies of lawyers decide to launch and finance their own network, RPVA, in 2007. The clerks of the commercial courts, with liberal status, also set up their own systems. In Austria, not only does the ministry integrate the legal professions into its platform, but it also provides them with financial incentives to operate it, see Koch and Bernroider (2008).

The integration of its information system in the federal government's one is another feature of Austrian justice. The ministry benefits the government's pooling policy of R&D and infrastructure services, which are managed by the BRZ. One key reform, on electronic communication with public bodies[8] in 2004, helps modernize justice systems like any other one of the public administration.

7 Conclusion

Cumulative spending data of France and Austria corroborate their respective information system maturity system index. Such an index may therefore be a valid proxy of the IT asset's value, and can substitute to spending data when perimeter gaps prevent their comparison.

For 9 out of 13 countries, the DEA stage suggests that investing in IT positively contributes to reduce disposition times, hence to justice efficiency. That is not a clear-cut outcome. Disaggregating the single maturity index brings results that are even harder to interpret. It is still difficult to determine the proportion and nature of IT contribution, because non-quantifiable variables also play significant roles. Indeed, entrusting IT projects to an inter-ministerial entity subject to market rules seems to be a factor of success in the Austrian experience, while the regulatory framework seems to constitute a factor of failure in the French one.

We propose three avenues for improving the understanding of the factors of efficiency of judicial IT. They all require adding new questions to the two-year survey cycle conducted by

[8] *Bundesgesetz über Regelungen zur Erleichterung des elektronischen Verkehrs mit öffentlichen Stellen (E-Government-Gesetz – E-GovG)*, BGBl. I Nr. 10/2004.

the CEPEJ.

The first avenue is to enrich and fine-tune questions relative to IT policy to understand how much the spending mix within IT per type of functionality, between innovation and legacy support, or between investment/operations, etc... and the level of integration/interoperability weigh on efficiency.

The second avenue is to build a proxy of normative density through some counting, of words, articles or pages, of legal instruments. For instance, the number of pages dedicated to procedural law and judicial organization is 7.31 times higher in France than in Austria. The underlying assumption is that, the denser the procedural norm, the more complex the case management system, and/or the longer the disposition time.

A third line of research is to build an attitudinal and behavioural index of stakeholders towards judicial IT and the very principle of replacing human assets with IT assets to foster efficiency of the judiciary. It would be built in such a way that reducing its value would entail efficiency gains. It might explain why an information system would not be mature, or how a country would miss the opportunity to reduce human assets despite a mature information system.

Such indices could then be used as additional inputs to a DEA.

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8 Appendices

8.1 Python code usage

The material is available at: DEA_Shapley Repository. The package `Shapley` must be imported first:

```
from Shapley import ShapleyModel
```

Then, data are loaded with `pandas` (excel, csv, etc.):

```
# Data
import pandas as pd
import numpy as np
cepej = pd.read_excel('cepej_2018.xlsx', index_col=0)
cepej = cepej.dropna()
cepej.head()
```

Then, we define the inputs ($y1$ and $y2$) and the outputs (X). Output vectors are concatenated into Y:

```
# Inputs and Outputs
y1 = 1000 - cepej['civil disposition time'].to_numpy()
y2 = 1000 - cepej['criminal disposition time'].to_numpy()
Y = np.column_stack((y1, y2))
X = cepej[[
        "judges",
        "non-judges",
        "information system maturity index", # this column is not used if
    the next 4 are
        "information tools",
        "productivity tools",
        "communication tools",
        "IT project governance"
        ]].to_numpy()
```

To instantiate the model, 3 parameters are necessary:

```
g_inputs = np.ones((X.shape[1]))
g_outputs = np.ones((Y.shape[1]))
constraint = "DRS"            # select "VRS" or "CRS" or "IRS"
```

Once the 3 parameters are saved, the model can be instantiated:

```
model = ShapleyModel(outputs = outputs, constraint = "DRS", g_inputs =
    g_inputs, g_outputs = g_outputs)
```

Before fitting the model, it is possible to print the scores of the directional distance function:

```
DDF_results = model.dea_ddf(X,Y)
columns = ["DDF"]
df = pd.DataFrame(DDF_results, columns=columns)
df['Rank'] = df['DDF'].rank(ascending=True)
display(df)
```

Then, the model is fitted by specifying the method for the computation of the contributions of each dimension X to the DDF:

```
df = model.fit("shapley",X,Y)  # Otherwise Choose "ES" for equal surplus
   or "permutation" to compute the feature importance
```

The dataframe `df` can be printed with absolute contributions are relative ones (in percentages):

```
columns = [
       "judges",
       "non-judges",
       "information system maturity index (this column is not used if the
   next 4 are)",
       "information tools",
       "productivity tools",
       "communication tools",
       'IT project governance'
       ]
contrib_df = pd.DataFrame(df, index = cepej.index, columns = columns)
row_sums = contrib_df.sum(axis=1)
contrib_pourcentage = contrib_df.div(row_sums, axis=0) * 100
print("Absolute Contributions:", "\n")
display(contrib_df)
print("Contributions (%):", "\n")
display(contrib_pourcentage)
```

The last technique is the permutation method. Each input of X is randomly permuted (30 times), then the score is averaged and compared with the total value of the DDF. Then, this is not a measure of attribution (or contribution) but rather a measure that indicates whether a feature may increase or decrease the DEA score: DEA score minus the mean of DEA with permutations of the inputs. If the score is positive then a feature contributes to increase the DEA score (then to increase inefficiency), and conversely.

```
df_permutation = model.fit("permutation",X,Y)
contrib_df_permutation = pd.DataFrame(df_permutation, index = cepej.index,
    columns = column)
display(contrib_df_permutation)
```

8.2 Technical efficiency by country (DDF) - Constant, increasing or variable returns

Table 8: Judges/non-judges/Single IT index

Country	CRS	rank	IRS	rank	VRS	rank
Austria	27.606	13	1.623	9	21.614	12
Switzerland	9.469	4	1.163	6	3.440e-13	1
Germany	23.818	12	1.868	11	22.096	13
Denmark	5.664e-12	3	8.627e-12	1	6.817e-12	2
Spain	19.799	9	3.198	13	17.117	9
Finland	19.669	8	1.034	5	18.716	10
France	14.168	7	0.634	4	3.082	5
Italy	22.585	11	2.327	12	13.937	8
Netherlands	4.956e-12	1	9.539e-12	2	7.846e-12	4
Norway	5.811e-12	2	1.189e-11	3	7.007e-12	3
Poland	13.345	6	1.546	8	12.335	7
Portugal	22.555	10	1.500	7	21.380	11
Sweden	12.649	5	1.818	10	11.233	6

Table 9: Judges/non-judges/IT sub-indices

Country	CRS	rank	IRS	rank	VRS	rank
Austria	1.623	7	1.266	7	0.364	6
Switzerland	1.163	4	0.814	5	9.382e-12	3
Germany	2.008	10	1.868	11	1.986	11
Denmark	8.629e-12	1	1.274e-11	1	8.762e-12	1
Spain	3.472	13	3.198	13	3.409	13
Finland	1.361	5	1.034	6	1.034	7
France	2.066	11	0.634	4	9.091e-12	2
Italy	3.330	12	2.327	12	2.327	12
Netherlands	9.543e-12	2	1.143e-11	2	1.020e-11	4
Norway	1.049e-11	3	1.966e-11	3	1.044e-11	5
Poland	1.695	8	1.546	9	1.546	9
Portugal	1.527	6	1.500	8	1.500	8
Sweden	1.818	9	1.836	10	1.697	10

Except for France, the different computation modes of returns do not significantly upset country rankings. It is likely this type of algorithm is of lesser importance than the choice of inputs, to the extent some hardly quantifiable factors of efficiency are not apprehended by DEA.

8.3 Methodology for comparing IT expenditure in France and Austria for their justice system

For French figures, and for the years up to 2007, we rely on the documents examined in the National Archives, relating to the period up to 1997, the Senate Justice report of 2004, the 2003-2007 master plan, and the opinion of MP Garraud on the justice annex to the finance bill for the year 2008. Linear interpolations are carried out for the few years without data. 2008 is the pivotal year in the methodology, the year from which IT expenditure is isolated in the annual performance reports (in French : RAP). These RAPs are implemented under the new organic low on finance laws (LOLF) and annexed to the bill relating to management results and approving the accounts for the year. From 2008, RAPs of the four "programs" of the justice "mission" have been exploited. Program 310 "Conduite et pilotage de la politique informatique" includes IT credits under the heading "action informatique ministérielle"; program 166 "Justice judiciaire" includes, under the heading "Soutien", the operating credits allocated to the so-called local-initiative IT ; program 107 "Administration pénitentiaire" includes IT expenditure in the sections "Administration pénitentiaire", "Accueil et accompagnement des personnes placées sous main de justice" and "Soutien et formation"; program 182 "Protection judiciaire de la jeunesse" has isolated its IT expenses only since 2013, under the headings "Mise en oeuvre des décisions judiciaires" and "Soutien". Each time executed payment credits are selected. IT expenses of the State Council, which manages administrative courts, must also be added. Figures are available only from the LOLF (2006). IT expenditure appears in the RAP of program 165 "Conseil d'Etat", which separates it between investment expenditure and operating expenditure. We rely on the annual performance report of program 165 ("Conseil d'Etat et autres juridictions administratives"), which distinguishes between operating expenses and investment expenses for IT. These expenses mark an average annual increase of 10 % and we extrapolate backwards, again for lack of anything better, this progression over the previous period. After this last adjustment, we convert to today's euros using the online converter of the statistics office (INSEE), then divide by the French population, including overseas, of the corresponding year, to obtain per capita expenditure. We then cumulate from 1971 to 2023.

For Austrian figures, we rely on archive documents of the Federal Chancellery (BKA), for the period before 1988, see BKA (1972, p. 64), BKA (1978, p. 106), BKA (1984, p. 144), the article of Bauer and Graf (2003, p. 106) for the period 1997-2003, the IT budgets taken from joint official presentations of the ministry and the BRZ for the years 2005 to 2007 (BMJ, 2005; BMJ, 2006; BMJ, 2007) and the expenses incurred appearing in the annual accounts available online of the company BRZ, for the subsequent years, consulted on https://www.brz.gv.at/wer-wir-sind/organisation.html. The latter in fact systematically

give the share of the Ministry of Justice in the turnover (the ministry has no other significant IT subcontractor). The absence of IT-related documents in State Archives (Staatsarchiv) which date back to 1974 and the impossibility of consulting documents within the Ministries of Justice and the Interior lead to some approximations.

To reconstruct the IT expenditure accumulated over time intended for the criminal record, we cross-check a document that provides with budgetary projections for the criminal record in the 1970s, see BKA (1972, p. 64) with another one which provides with expenditure made for the IT of the entire judicial police mission of the Ministry of the Interior, see BKA (1984, p. 152). The annual average of the expenses of one compared to the expenses of the other over the years 1978, 1980, 1982 gives a rate of 15 %, which we then project until 1988. Functional scope and IT spending are assumed to be stable from 1988 in today's euros. For each year, expenditure is added to that of the judicial and penitentiary services.

The Austrian judicial services represent 57.9 % of the ministry's budget. The share of the Austrian IT expenditure devoted to the land registry and the commercial register is not available. On the other hand, the responses to the CEPEJ biennial survey distinguish production volumes by type of decision. Legal commercial or land announcements, which constitute legal decisions, therefore appear there, and represent in 2018 overall 45 % of production, see CEPEJ (2020b, pp. 61–66). The IT effort devoted to judicial services is assumed to be proportional to production, this rate to be constant over time, and the intensity of the effort to be the same for the different functions, that is, computerizing 1000 court decisions in land matters, for example, costs the same as computerizing 1000 court decisions in civil or criminal matters. The resulting comparable base to France for judicial services is equal to 57.9 % x (100 – 45) % = 23.5 % of the IT budget of the Austrian justice system, to which the share of IT expenditure of prison administration and youth judicial protection must be reintegrated.

8.4 IT spending compared between France and Austria - Longitudinal study

Figure 5: Yearly IT spending in constant euros and at equal scope

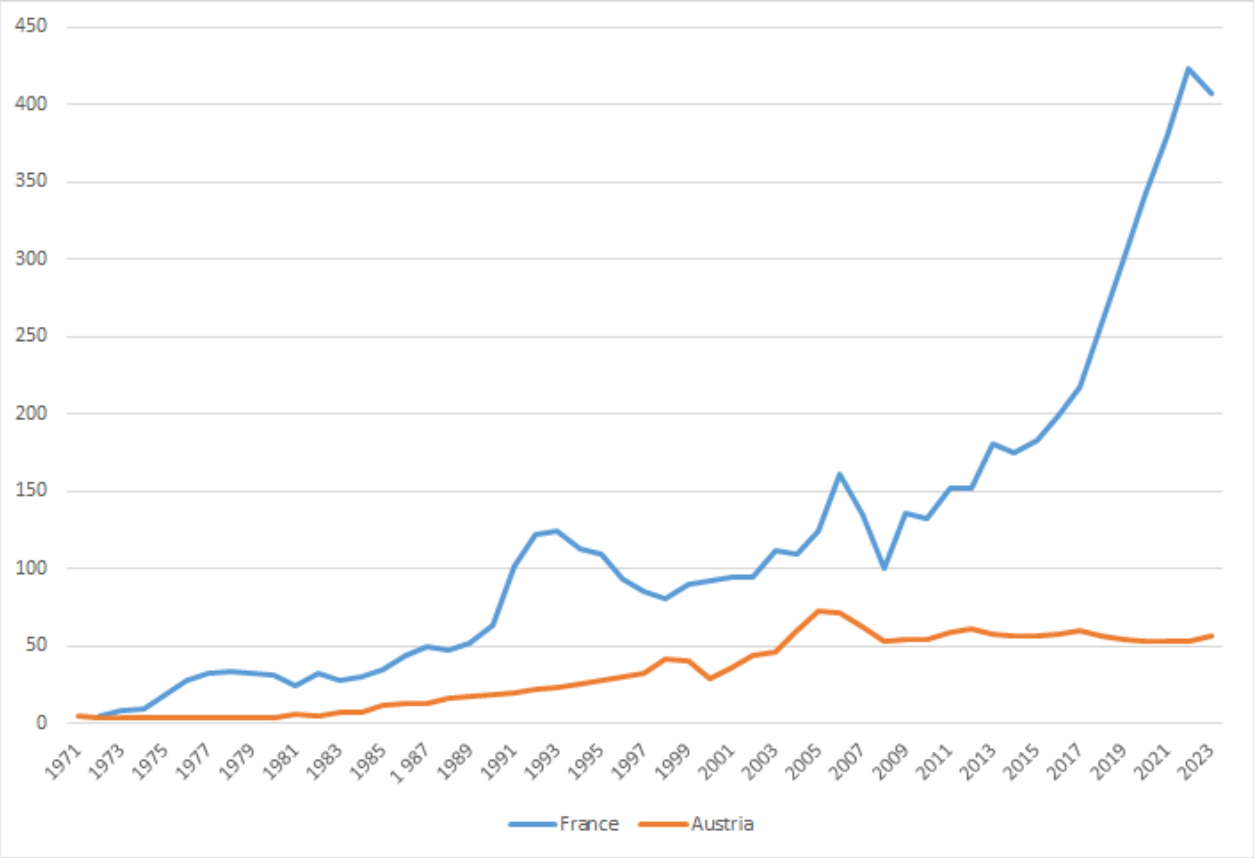
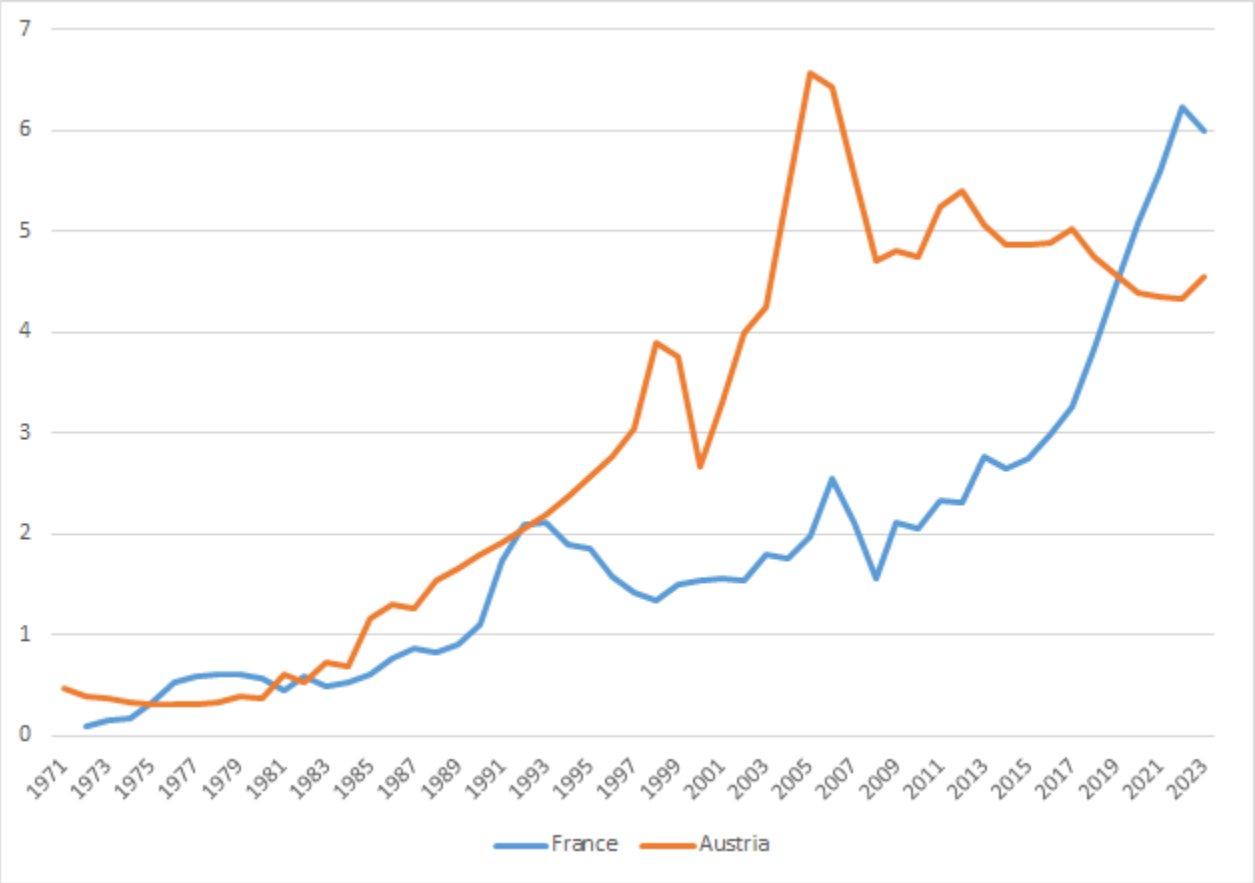


Figure 6: Yearly IT spending in constant euros and at equal scope per inhabitant



Underlying calculations are available in file IT_spending.xlsx at:DEA_Shapley Repository.