

## Article

# Ghosts in the Machine: How Big Data Analytics Can Be Used to Strengthen Online Public Procurement Accountability

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**Abstract:** The core of sustainable public procurement lies in its ability to stem uneconomical public expenditures that waste taxpayer money and stifle social trust and development. The external audit of public procurement proves problematic since current research fails to provide sufficient empirical studies aimed at identifying procurement fraud. The development of online portals with embedded e-procurement solutions, along with the big data revolution, open new horizons and allow us to reveal trends otherwise impossible to spot, such as transactions achieved in an exclusive commercial relationship, in which a vendor engages only with a single public entity. By using innovative data acquisition techniques, our research encompasses 2.25 million online direct public procurement procedures conducted in 2023 using the Romanian portal for public procurement, totaling EUR 3.22 billion. By aggregating databases obtained from various public sources, our analysis achieved remarkable granularity, using over 112 million data elements—50 pertaining to each transaction. Research results indicate a unique sub-population of public procurement procedures—those conducted with “in-house” vendors totaling 14.28% of all direct public acquisitions and which is significantly differentiated along the entire list of analyzed criteria—financial, geographical, statistical, or risk-wise—illustrating a troubling phenomenon: possible gerrymandering of the online public procurement landscape, which, at least in theory, resembles a perfect market, by cultivating preferential commercial relations, thus affecting the legality, regularity, and economical aspects of public procurement.

**Keywords:** public procurement; fraud detection; public sector; external public audit; supreme audit institutions; big data analytics; sustainable procurement



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## 1. Introduction

While not a new concept altogether, since modern governments usually aim to steer important social and economic developments, either through regulatory or financial levers, sustainable public procurement enriches the traditional value-for-money perspective with additional social, economic, and environmental facets, with equal emphasis on all three dimensions. Along with them, sustainable procurement practices encompass the essential ingredients of sound public procurement: transparent, fair, non-discriminatory, competitive, accountable, and efficient use of public funds.

The public procurement domain is extremely susceptible to fraud [1,2] and, given its significant economic impact in every country [3], it has garnered considerable research interest in recent decades. One of the latest solutions for reducing procurement fraud risk is the employment of online portals [4], which ensure transparency and open up the process to public scrutiny. Furthermore, the recent strive towards open data has contributed to public accountability, empowering NGOs and citizens, and putting the

spotlight on oversight bodies [5], all conducive to reaching SDG targets pertaining to access to information and accountable institutions. The European Parliament and Council Directive on Public Procurement encourages member states to employ electronic methods for public procurement and communication with bidders [6]. In this regard, some EU countries have developed online public procurement portals [7–11] that prove to be essential tools in furthering sustainable procurement targets, offering participants and, in some cases, the public, ever-expanding datasets.

Once the relevant data is available, the research approach regarding fraud risk is diverse, from the use of simple statistical laws to identify anomalous transaction values [12], to employing network science and the PRISMA method [13] or the Pattern-Based Anomaly Detection in Graphs method [14]. Other researchers propose using decision support systems based on clustering, regression, and other advanced data science methods [15] to support public authorities tasked with fraud investigations.

Attention is also given to the human side of procurement fraud [2,16], where the diamond theory offers clarity in this regard: pressure, opportunity, rationalization, and capacity are the determining elements of committing fraud. Nonetheless, empirical studies tackling procurement fraud are scarce [13].

Although even the prospect of an external public audit can significantly reduce public procurement excesses [17], the actual impact of Supreme Audit Institution (SAI) audits in this regard remains difficult to assess [18,19], highlighting the need to overhaul the entire audit approach to produce palpable results.

Aside from tackling the public procurement fraud phenomenon, our research entails a dive into an actual and interesting field, namely the use of big data analytics in public external audits. By adapting to auditees' and society's progress, SAIs welcome the big data revolution as an instrument aimed at restoring and maintaining the legitimacy of the audit function [20,21]. Similarly, audit company leaders confirm a generalized external pressure to favor data analytics over classical audit tools [22], an evolving trend starting in the 1960's when audit sampling was introduced [23], as a response to critique of the traditional audit evidence collection methods in an age where transaction volumes started increasing exponentially.

The Romanian online catalog belonging to the Electronic System for Public Procurement (ESPP) is used for contracting direct public acquisitions and emulates the conditions of a competitive market, where public buyers' necessities meet a plethora of similar vendor offers, creating the conditions for maximizing public money returns. Such a construct benefits from all the presumptions of a perfect market—identical or similar products, a large number of sellers and buyers, free market entry and exit, fully informed participants, and a lack of external influence.

These are the perfect conditions for fierce competition, as well-informed buyers, benefiting from the platform's facilities, will always choose the most advantageous offer, while a competitive seller will receive orders from all the buyers interested in that particular good/service/work. Conversely, an exclusive commercial relationship, where a seller develops relations with only one buyer, cannot be perceived as feasible in such a market and indicates, simply through its nature, significant fraud and uneconomical use of public resources risks.

Such competitors, having their offers found acceptable by only one buyer and no other, are veritable "*ghosts in the machine*", seemingly not abiding by the rules of competition and free market. These occurrences must determine auditors and researchers to identify, analyze and characterize them.

Using specially designed software, we set out to realize a detailed analysis of online direct public acquisitions conducted in 2023 in the Romanian ESPP. We aimed to identify and characterize transactions that belong to an exclusive commercial relationship—"*one seller to one buyer*", along with the main characteristics of the "*in-house*" vendors.

For this purpose, all of 2023's direct online public procurement procedures and their related data—over 112 million data elements—were analyzed—50 for each of the 2.25 million

online direct public acquisitions, placing our research in the big data analytics domain. In this regard, an interesting nuance for audit data relates to using more diverse data instead of more of the same data [24], by incorporating non-financial and even unstructured data stemming from outside the auditee. Our research integrates four different data sources: ESPP, financial reporting data, general taxpayer and public entity data obtained from the Finance Ministry, thus encompassing public procurement data, geographical, statistical, and financial data pertaining to sellers, buyers, and their ESPP transactions.

Our investigative efforts illustrate an important and valuable practical approach to auditing public procurement in a manner that supports earlier research conclusions [25], highlighting the resemblance between big data analytics and academic research techniques: both require collecting and testing copious amounts of data using statistical software to identify patterns and relationships between components, aiming to obtain sufficient proof to confirm or deny a hypothesis.

The purpose of this paper is to provide an empirical approach to assessing public procurement fraud risk, aimed at identifying exclusive relationships within the ESPP and highlighting their distinctive characteristics as compared to the entire 2023 transactional database. Following the Introduction, Section 2 contains a detailed methodological description, both from a risk assessment standpoint as well as dealing with the specific IT challenges posed by obtaining, processing, and analyzing the relevant data. Section 3 is dedicated to presenting the research results, structured on the three research dimensions envisaged, while Section 4 discusses these results, aiming to offer insight on their proper interpretation. Finally, Section 5 offers conclusions on the “1-on-1 trades”, their specifics, and the associated fraud risks, and indicates several future research dimensions needed to better leverage the use of big data in public procurement fraud analysis.

## 2. The Research Methodology

The first research dimension entails the exploratory analysis [26] of the 2023 Romanian direct public acquisitions conducted through ESPP, using both specially designed software and mainstream database management platforms, aimed at identifying transactions conducted within an exclusive commercial relationship—“one vendor to one buyer”, revealing a potential departure from the basic principles of transparency, fairness, competition, and efficiency that underpin sustainable public procurement.

Subsequent to identifying this sub-population, our research consisted of a comparative analysis with the entire population under all significant aspects (number of transactions, total and average value) in order to highlight any traits that significantly differentiate them—frequency of transactions with companies or individuals, proximity with the vendors, the existence of filed vendor financial statements. Furthermore, our research encompasses a comparative risk assessment of the whole transactional database and the exclusive relationship category (transactions conducted on weekends, at unusual hours, those finalized in a very short amount of time, buying bundled goods or predefined labels), based on the hypothesis of a greater fraud risk pertaining to “in-house” acquisitions.

Our third research dimension correlates the ESPP transactional data with the main financial indicators pertaining to the financial statements filed on 30 June 2023 (current and non-current assets, inventories, sales income, profit/loss, and number of employees).

Since one of the most difficult tasks for SAIs related to big data analytics is identifying its proper use scenarios [27], we set out to illustrate, as exhaustively as possible, the approach to investigating public procurement conducted in an exclusive commercial relationship without claiming to cover the entire possible spectrum of analysis and, as such, to improve the perception of utility for big data analytics in audit, which proved a determinant factor ( $r = 0.803$ ) in their adoption by individual auditors [28].

The first step needed to conduct our research was obtaining the relevant data. While the general company information and their financial data were downloaded from the national Open Data Portal [29], this was not the case for the public procurement transactional data and the public entities’ general information. In this regard, we must stress the growing

contribution of big data and open data to the economic, administrative, and scientific added value [30,31], a veritable “21st century raw material” [32] that our research manages to fructify.

The other necessary datasets were obtained by accessing the ESPP portal’s direct online acquisitions subsection and the Ministry of Finance portal [33], in the case of public entities’ general information. From this perspective, we can assert that, although these datasets do not meet the criteria of open data, they are sufficiently accessible to the public to properly attain their publication purpose.

Nonetheless, the ESPP portal restricts downloading comma separated value files (csv) to no more than 2000 records each, leading us to create several transaction value tranches for each calendar day to be able to download the results. Since such an undertaking would be extremely time-consuming and prone to human error, we created a software robot designed for web-scraping, using AutoIT V3, illustrated in Appendix A.

Web-scraping is defined as the procedure for automatically extracting data from websites, using dedicated software [34]. In such an interaction, a software robot simulates human behavior in interaction with the website, accesses the desired pages, and extracts the target data [35].

In our case, the web-scraping robot downloaded each transaction value tranche, starting with the first day and month of 2023 and repeating its instruction set through 31 December.

The software robot composes each calendar date from his components (day, month, year, and the proper separators—lines 1–26), and the clipboard-stored value (line 27) is then filled in the corresponding ESPP section (lines 28–31), subsequently commanding the search (line 33). Based on determining the color of a certain section of the webpage, the robot then waits for the website to return the search results, ensuring that the page has properly loaded before continuing its instruction set (lines 35–39). The returned results are then compared to meeting the maximum download quota, and if the criterion is met, download instructions are executed (lines 50–55), including the confirmation for post-download page loading (lines 56–59). The pages containing more than 2000 results determine the robot to write the date into an Excel sheet opened in advance to signal the need for human intervention to reconfigure the upper and lower interval values to reach a downloadable result (lines 41–49). The process is then reinitiated by increasing the day value by 1 and, when it reaches 31, by increasing the month value by one and resetting the day count to 1 (lines 3–26).

Following these steps, 16,073 csv files were downloaded, containing all of the direct online public acquisitions conducted through ESPP in 2023.

We used Ms. SQL Server 2017, in connection [36] with SQL Server Management Studio 19 (SSMS), to conduct our data analysis procedures, while the correlational analysis was done using IMB SPSS 26.

Data analytics researchers agree that 80% of all time dedicated by practitioners to this process is lodged in the data preparation stages [37–40]. This hypothesis was also verified during our research, since the 16,073 csv files went through a laborious and, at times, repetitive process of import, cleaning, preparation, and validation, all needed for conducting proper data analysis—Figure 1, which can be summarized as follows:

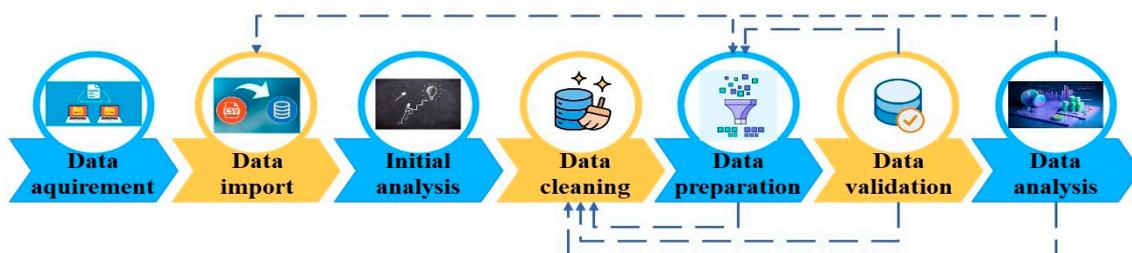


Figure 1. Data analytics process.

- csv file import, which SSMS classifies as “flat files” [41]—files that can be understood and manipulated both by humans and computers, with an intuitive structure compared to the complexity of relational databases. For this purpose, we constructed SQL queries based on the Bulk Insert declaration to call the Bulk Copy Program function [42], which is used to import data from the chosen files;
- Data cleaning, which includes the detection and exclusion of inconsistencies, in order to increase audit data quality [43]. This stage is considered a must, since in other studies, around 5% of the data collected was found to be “dirty” [44]. In our case, it was necessary to eliminate duplicate data, transactions placed on the upper or lower selection interval values. Furthermore, to concatenate several databases on common keys, we needed to separate fields offered as a merged value, fiscal code and entity name, both for the seller and the buyer, and the Common Procurement Vocabulary (CPV) code and its description;
- Data preparation, an essential stage that confronts the researcher with the collected data, requiring a proper understanding of the knowledge it encapsulates. According to researchers [45], data preparation is an art on its own that cannot be superficially conducted or successfully automated because it encompasses an understanding of the real-world phenomena that the data describes, along with the purpose for its analysis. In this stage, the transactions that had another state than “offer accepted” were excluded from our analysis;
- Data validation, which is generally associated with certifying data quality [46–48], is the process of obtaining adequate assurance that the data is exact, actual, available, correct, consistent, and complete. Our validation process was composed of two stages:
- Internal validation, which entailed a gap analysis of the consecutive unique transaction codes. This revealed several groups of transactions that have been omitted by the automated extraction process, but also unique transaction codes that are simply missing from the system, probably due to manual deletion. In this manner, we comprised a complete transactional dataset for 2023 direct online acquisitions;
- External validation, using for comparison the complete list of public entities (both institutions and publicly owned enterprises), aimed at eliminating transactions pertaining to NGOs, religious organizations, or other private entities that are outside of SAI’s field of competence.

Following this laborious process needed to prepare the data for analysis, we obtained 2.25 million online direct public acquisitions totaling 15.94 billion RON, the equivalent of 3.22 billion Euro, as per the average 2023 exchange rate [49].

As shown in Table 1, we employed a series of Transact-SQL queries to first extract the list of distinct ESPP seller–buyer pairs from the main database `tbl_ESPP`, counting their transactions and summing up their values (line 1). Subsequently, we grouped the results on each seller (line 2) and extracted only those sellers whose count of beneficiaries was equal to 1 (line 3). The obtained list was then compared with the original database, and records with identical seller fiscal code values were extracted (line 4). For reading convenience, the field names illustrated in Table 1 have been changed to their English equivalents.

**Table 1.** Transact-SQL set of instructions for extracting exclusive sellers.

Line No.	T-SQL Instructions
1	<code>SELECT Seller, Buyer, COUNT([Transaction amount]) AS No_of_transactions, SUM([Transaction amount]) AS Total_value INTO #temp FROM tbl_ESPP GROUP BY Seller, Buyer</code>
2	<code>SELECT Seller, COUNT(Buyer) AS No_of_buyers, COUNT([Total_value]) AS No_of_transactions, SUM([Total_value]) AS Total_value INTO #temp2 FROM #temp GROUP BY Seller ORDER BY No_of_buyers DESC</code>
3	<code>SELECT #temp2.Seller INTO #temp3 FROM #temp2 left join #temp ON #temp2.Seller = #temp.Seller WHERE No_of_buyers = 1</code>
4	<code>SELECT * FROM #temp3 left join tbl_ESPP ON #temp3.Seller = tbl_ESPP.Seller#</code>

This dataset was analyzed following the research dimensions described in order to highlight the characteristics of the entire population along with those belonging to transactions made under an exclusive commercial relationship.

### 3. Results

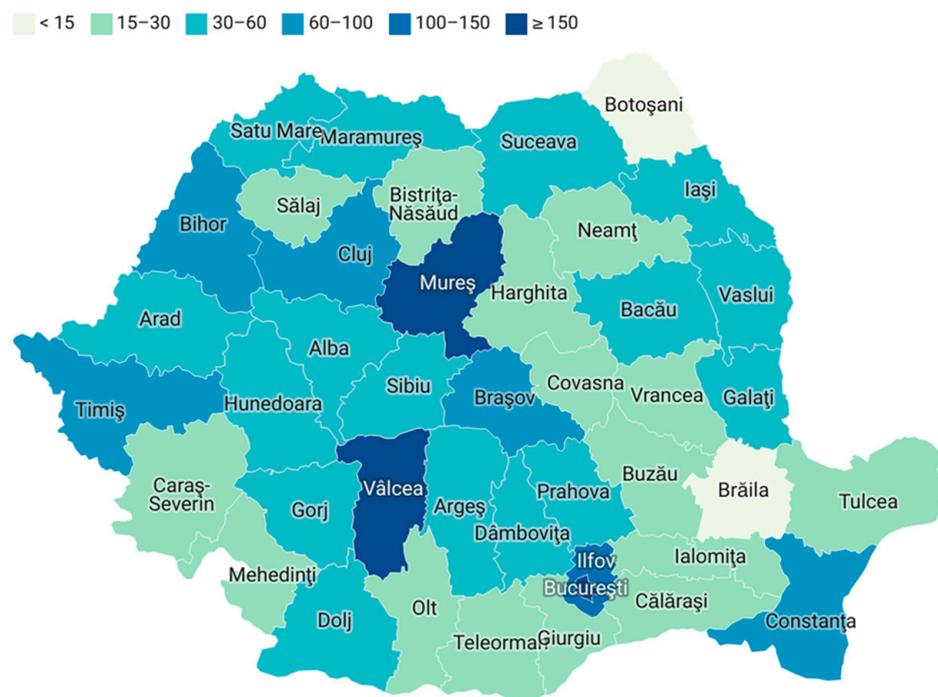
#### 3.1. Identifying Exclusive Contractors

We set out to identify those sellers engaged in exclusive commercial connections within ESPP, since such a privileged relationship indicates, on the one hand, that public acquisitions can be discretionarily directed and inefficiently conducted and, on the other, that the seller does not have a significant footprint in its respective market and is not preoccupied with developing it further by interacting with other public authorities/entities.

We queried the resulting database using the criteria “1 seller to 1 buyer” and the results showed the existence of 93,723 transactions totaling 2.28 billion RON (460 million euro) in which the contractor has not delivered goods/services or executed works for any other public beneficiary. This was the case for 7460 public entities that have granted exclusive contracts to one or more of the 26,311 sellers engaged in such practices.

Online public direct acquisitions granted to “in-house” bidders make up 14.28% of the total value of 2023’s ESPP direct procedures and, as such, pose significant challenges when auditing the public procurement domain, since this type of relation can imply, aside from its legality, conformity and economical aspects, also ethical and conflict of interest matters that generally fall outside an external auditor’s jurisdiction. Nonetheless, these are important aspects to consider when investigating any type of fraud.

The geographical distribution of 1-to-1 trades—Figure 2—demonstrates the need for a differentiated approach, tailored to each region, starting with the ones where the phenomenon peaked and working towards those where it is still a marginal occurrence.



**Figure 2.** Geographical distributions of 1-to-1 trades—RON million.

#### 3.2. Exclusive Contractor Transaction Characteristics

Compared to the entire 2023 transactional population meta-data—Table 2, trades stemming from exclusive relations—Table 3 make up 4.17% of the total number of 2023 online direct acquisitions, while their value share is 14.28%, signaling a significantly higher

average value of the 1-to-1 trades: 24,289.65 RON (4910.53 euro) as compared to the overall average value of 7098.56 RON (1435.10 euro).

**Table 2.** 2023 ESPP direct acquisitions meta-data.

	Indicator	No. of Transactions	Total Value mln. euro	Average Value	% of Transactions	% of Total Value
Contractor type	Total	2,245,446	3222.43	1435.10	100.00%	100.00%
	Unidentified	11,499	16.53	1437.52	0.51%	0.51%
	Individuals	31,817	69.72	2191.28	1.42%	2.16%
	Companies	2,202,130	3136.18	1424.16	98.07%	97.33%
	Companies with filed f.s.	2,107,457	2953.33	1401.37	93.85%	91.65%
	Companies w/out filed f.s.	137,989	269.10	1950.16	6.15%	8.35%
	Local contractors	1,245,472	1934.47	1553.20	55.47%	60.03%
	National contractors	988,475	1271.43	1286.25	44.02%	39.46%
Risk indicator	Transactions granted within one minute of publication	40,348	52.51	1301.43	1.80%	1.63%
	Transactions granted within five minutes of publication	155,331	245.96	1583.46	6.92%	7.63%
	Public works granted in under 60 min	20,394	273.82	13,426.50	0.91%	8.50%
	Bundled goods	250,300	195.54	781.22	11.15%	6.07%
	Predefined labels	2566	7.90	3078.72	0.11%	0.25%
	Transactions published at unusual hours	13,747	21.75	1582.16	0.61%	0.67%
	Transactions initiated/finalized during weekends	13,764	18.25	1325.92	0.61%	0.57%

**Table 3.** 2023 ESPP 1-to-1 direct acquisitions meta-data.

	Indicator	No. of Transactions	Total Value mln. euro	Average Value	% of Transactions	% of Total Value
Contractor type	Total	93,723	460.23	4910.53	100.00%	100.00%
	Unidentified	753	4.59	6095.62	0.80%	1.00%
	Individuals	7892	26.19	3318.55	8.42%	5.69%
	Companies	85,078	429.46	5047.84	90.78%	93.31%
	Companies with filed f.s.	78,692	396.23	5035.20	83.96%	86.09%
	Companies w/out filed f.s.	15,031	64.01	4258.53	16.04%	13.91%
	Local contractors	80,074	303.94	3795.74	85.44%	66.04%
	National contractors	12,896	151.71	11,764.11	13.76%	32.96%
Risk indicator	Transactions granted within one minute of publication	2622	9.51	3627.00	2.80%	2.07%
	Transactions granted within five minutes of publication	8239	62.55	7591.94	8.79%	13.59%
	Public works granted in under 60 min	3508	55.97	15,954.96	3.74%	12.16%
	Bundled goods	6317	9.83	1556.12	6.74%	2.14%
	Predefined labels	45	0.15	3333.33	0.05%	0.03%
	Transactions published at unusual hours	817	3.51	4296.21	0.87%	0.76%
	Transactions initiated/finalized during weekends	794	4.51	5680.10	0.85%	0.98%

As our other research dimensions entail a comparative analysis using the main contractor balance sheet indicators, we appended the information regarding the 70,000 unique sellers active on ESPP in 2023 with their 2022 financial statements, published on 30 June 2023. Our data shows the conclusion of 31,817 transactions with individuals that did not have a legal requirement to file financial statements with the fiscal authorities (1.42% of the total transactions and 2.16% of their value), as well as 11,499 transactions with companies that were not identified in the company registry put forth by the Finance Ministry through the national Open Data Portal. This confirms earlier conclusions regarding the need to improve the quality of open data published by public authorities [50,51].

Furthermore, only 2,107,457 of the total 2,202,130 transactions conducted with businesses pertain to companies that have observed the 30 June 2023 deadline for filing financial statements, since those not filed or filed late are not part of the published open data.

The first comparative analysis aimed at highlighting the characteristics of 1-to-1 public acquisitions refers to its geographical dimension—the county of origin for both the contractor and the public authority—since our professional judgement led us to associate such an exclusive commercial relationship with the proximity factor. Research results confirm this hypothesis, since 85.44% of 1-to-1 transactions are endemic to one county, as compared to the total population average of 55.47%. We must stress that, in making this analysis, we

associated the peri-urban area of Ilfov County with the capital city of Bucharest, since the geographical and economical aspects of the two are mostly intertwined.

While its numbers are lower than average, a distinctive trait of transactions conducted with national contractors is their average value—140% more than the 93,723 exclusive transactions average, which, in turn, is more than triple that of the overall average value. Inter-county transactions boast an average value of 58,188.59 RON (11,764.11 euro), 720% greater than the 2023 all-around average value.

Results also indicate a significant cleavage between the number and value of transactions conducted with sellers lacking 2022-filed financial statements—either not having such an obligation or not properly meeting it. While for the entire population, this category represents 6.15% of total transactions, respectively 8.35% of their total value, the exclusive relation statistics are significantly higher—16.04% of their number and 13.91% of their total value.

Given these results, we can safely conclude that the public acquisitions stemming from 1-to-1 relations paint a substantially different picture, especially if we consider their average value—242% greater—their geographical dispersion, and the type of bidders involved.

The next stage of our comparative analysis entails quantifying seven specific public procurement risk indicators based on the available data, defined as:

- acquisitions granted in one minute of their publication;
- acquisitions granted within five minutes of publication;
- public works granted in under 60 min;
- buying bundled goods;
- specifying predefined labels in the procurement description;
- transactions published at unusual hours—between 7 p.m. and 6 a.m.;
- transactions initiated or finalized during weekends.

Without exception, the seven risk indicators reveal, in the case of 1-to-1 trades, a uniquely defined sub-population. Five of the quantified risk indicators show significantly higher values—between 13% and 311% higher—while two risk indicators—buying bundled goods and using predefined labels in the procurement description—are far lower—between 40% and 88% lower. It seems that, although “*in-house*” transactions carry a far greater overall fraud risk, special consideration was given to details that could attract unwanted attention towards them.

In this regard, we must emphasize the 311% difference (when comparing transaction numbers), and, respectively, 43% when comparing total values, regarding the occurrence of public works granted within an hour of their publication, which indicates a concentrated effort to direct them to preferred bidders.

### 3.3. ESPP Transactional Data Correlation with Filed Contractor Financial Statements

Our third research dimension involves a comparative analysis of the correlation between the number and total value of ESPP direct acquisitions and each contractor’s financial statement, as reported for 2022.

Naturally, successful ESPP contractors will translate their achievements into solid business performance, positively affecting their main financial indicators. These correlations were indeed observed when analyzing the financial data of all 58,451 contractors who filed financial statements. The number of ESPP transactions and their total value positively correlates with all relevant balance sheet indicators: non-current assets ( $r = 0.264/0.200$ ,  $p = 0.000$ ), current assets ( $r = 0.344/0.275$ ,  $p = 0.000$ ), inventories ( $r = 0.430/0.246$ ,  $p = 0.000$ ), owner’s equity ( $r = 0.361/0.223$ ,  $p = 0.000$ ), sales income ( $r = 0.318/0.297$ ,  $p = 0.000$ ), net profit ( $r = 0.467/0.276$ ,  $p = 0.000$ ), and finally the number of employees ( $r = 0.386/0.226$ ,  $p = 0.000$ )—Table 4.

**Table 4.** ESPP trades correlation with the main company financial indicators.

Seller Category	Balance Sheet Indicator	Population	No. of Transactions		Total ESPP Sales	
			Pearson Correlation	Sig. (2-Tailed)	Pearson Correlation	Sig. (2-Tailed)
All contractors with filed financial statements	Non-current assets	58,451	0.264	0.000	0.200	0.000
	Current assets		0.344	0.000	0.275	0.000
	Inventories		0.430	0.000	0.246	0.000
	Owner's equity		0.361	0.000	0.223	0.000
	Sales income		0.318	0.000	0.297	0.000
	Net profit		0.467	0.000	0.276	0.000
	No. of employees		0.386	0.000	0.226	0.000
Non-exclusive contractors	Non-current assets	38,204	0.268	0.000	0.277	0.000
	Current assets		0.382	0.000	0.416	0.000
	Inventories		0.535	0.000	0.417	0.000
	Owner's equity		0.364	0.000	0.307	0.000
	Sales income		0.325	0.000	0.417	0.000
	Net profit		0.471	0.000	0.380	0.000
	No. of employees		0.400	0.000	0.318	0.000
Exclusive contractors	Non-current assets	20,247	-0.004	0.593	0.000	0.960
	Current assets		-0.002	0.752	0.002	0.814
	Inventories		-0.001	0.832	0.001	0.926
	Owner's equity		-0.005	0.492	0.001	0.880
	Sales income		-0.002	0.804	0.001	0.854
	Net profit		-0.006	0.391	0.005	0.499
	No. of employees		-0.005	0.479	0.001	0.861

These correlations are substantially stronger when we consider only those contractors that have not developed 1-to-1 relationships within ESPP. Thus, the average strength of correlations regarding the number of transactions increases by 6.36%, while the strength of correlations with the total value of public procurement procedures increases by 45.11%.

Nonetheless, the situation is completely different regarding the correlation of ESPP transactional data to balance sheet indicators for exclusive contractors. None of the naturally occurring positive correlations can be identified in their case since the ESPP transactional data and their 2022 financial statements are so disjointed that they are situated between  $r(20,247) = -0.006, p = 0.391$ , and  $r(20,247) = 0.005, p = 0.499$ .

Therefore, our research highlights some rather telling characteristics of the 2023 ESPP exclusive contractors, indicative of a higher fraud risk, since the naturally occurring economic correlations are not generally present within this sub-category.

#### 4. Discussion

The degree to which public procurement procedures observe the fundamental principles set forth by European legislation and ensure the maximization of benefits from using public money is a fundamental concern for society as a whole. Furthermore, while online public procurement portals with embedded e-catalogs contribute greatly to bringing to light otherwise opaque procurement procedures and ensuring, to a certain degree, the efficient use of public resources, they must also confer public trust in their internal control mechanisms, which should be designed and operated in such a manner as to ensure the legality and conformity of public acquisitions and minimize fraud risks.

Without exception, analyzing the characteristics of public procurement conducted within exclusive commercial relations revealed a distinctive sub-population, defined mainly by their increased average value—242% greater than the overall average. In this regard, while their weight in the total population is only 4.17%, their worth is much more significant—14.28%. Although some preference factor for known sellers can intervene, it should be procedurally shunned by the e-market features, ensuring fair competition between sellers and optimum transaction prices.

Additionally, the average value of nationwide transactions stands at 820% when compared to the 2.25 million transactions' average value, while the percent of transactions conducted with sellers without filing 2022 financial statements is almost double. Furthermore, research results confirm the proximity hypothesis, since 85.44% of exclusive transactions are endemic to one county, as compared to the overall population, where local transactions represent only 55.47%. While a certain degree of proximity bias is objectively explainable, both from the sellers (given the increased shipping cost for goods and the practical aspects of displacing resources needed to provide services and execute public works further away from company headquarters) and the buyers (taking into consideration the timeliness factor, local seller certification requirements, etc.), objectively these arguments should not differ between exclusive and non-exclusive commercial relations.

The results of our second research dimension illustrate increased risks for transactions occurring in 1-to-1 relations, since for 5 of the 7 analyzed risks, indicators show increases between 13% and 311% (transactions granted in one minute/five minutes of publishing, public works granted in under 60 min, transactions published at unusual hours, transactions initiated/finalized during weekends). Conversely, the bundled goods and predefined labels risk indicators are much lower—between 40% and 88%—which can be attributed to whitewashing efforts to avoid attracting unwanted attention to these transactions. As was the case with contractor specifics and transaction meta-data, these deviations cannot be explained outside of a fraudulent behavior hypothesis. For instance, 311% more public works were attributed to exclusive contractors within 1 h of publishing, and 55.56% more transactions were finalized in one minute of publishing. Since ESPP is a virtual marketplace, physical proximity with the buyer or previous relations cannot be factored in to explain such differences.

Since the first two research dimensions reveal a series of distinctive traits for public acquisitions attributed to exclusive contractors, both regarding their general characteristics and the associated risk factors, our correlational analysis of 2023 public procurement data and 2022 contractor financial data reinforces our findings: no statistical connection could be identified between ESPP activity and the main contractor balance sheet indicators in the case of exclusive contractors. These transactions seem to elude any supply-and-demand logic and are attributed to contractors with financial indicators that cannot be statistically considered as naturally occurring. Inherently, this latter approach suffers from the limitations of comparing statistics from two different financial periods since the 2023 financial statements are not yet filed. As a result, the analysis is influenced by the potential lack of correlation specific to newly funded contractors that either did not file 2022 financial statements or the filed statements are not illustrative of their 2023 activity. Nonetheless, this caveat should influence both exclusive and non-exclusive contractors in the same manner, which maintains the relevance of our comparative analysis.

A distinction must be made both on the agency-specifics and their domain. Since the public procurement laws set aside certain domains—defense contracts, exclusive rights contracts, or own-enterprise contracts—and the ESPP provides a unique workflow for public e-procurement, any agency-specific approach to public procurement is leveled out, providing researchers with a uniform transactional database. However, domain specifics could impact the likelihood of fraudulent behavior. Specialized markets such as pharmaceutical, aeronautical, or large infrastructure projects come with their own breeds of endemic factors, whereas certain domains are more prone to fraud than others. Future research into segregating these fields could yield interesting results.

## 5. Conclusions

As the post-COVID experience showed, achieving the SDGs depends on the capacity of public institutions to promote efficient and effective public spending and limit corruption, especially by employing adequate accountability and oversight mechanisms. Furthermore, transparency and the adoption of emerging technologies are key issues for sustainable

public procurement, and the use of e-procurement has the potential to become a game changer in this regard.

The available data led us to the conclusion that public procurement procedures conducted within exclusive commercial relations entail a significantly higher fraud risk and must be thoroughly investigated both by supreme audit institutions, called upon to provide assurance for the legality, conformity, and economical use of public resources, and by other competent national and European authorities. Even if audit data analytics is in an incipient stage [22], SAIs must find resources to employ the whole spectrum of big data analytics when dealing with online public procurement procedures.

Although our research is current, it is based on 2023 historical data, and as such, a real-time approach using built-in risk detection mechanisms is necessary in order to prevent public procurement fraud, as other researchers previously concluded [52].

While fraud-related research is an established domain, the use of emerging technologies for this purpose and the study of e-procurement platforms and their effects on fraud risks are quite novel developments, starting in 2018, and are approached by few researchers [53]. The literature reviews available [13,53–55] reinforced this conclusion and enabled us to better illustrate our contribution to enriching the current research.

E-procurement is tackled by some researchers, albeit mainly regarding its contribution to decreasing fraud risks [4,56,57] and rarely regarding its own weaknesses that can lead to fraudulent behavior [58]. Nonetheless, emerging technologies such as e-procurement markets have the potential to significantly improve governance and accelerate efforts to achieve the SDGs.

Our research employs rarely used data collection techniques [55] and complements recent work that has unequivocally concluded on the link between diversity of beneficiary-contractor pairs and governance quality, while the variance in geographical distance between them was mainly attributed to the degree of competitiveness of the procurement methods [59]. While these conclusions were drawn after researching 3.3 Million higher-value contracts published in the Journal of the European Union, they take into account the frequency of transactions between each buyer-seller pair and not their exclusive nature. Furthermore, since direct public acquisitions are essentially outside the scope of “public procurement procedures” given their lower values, our research is even more illustrative of a yet uncaptured phenomenon.

As such, our research results provide a unique insight into the online public procurement process and are relevant for the professional and general socio-economic environment. Furthermore, it contributes significantly to enriching the research literature in the external audit of public acquisitions and fraud detection using big data analytics.

Our study is the starting point for future research directions, which will include longitudinal and transversal dimensions, aimed at highlighting the effects of legislation on exclusive procurement relations and better understanding the European context of this phenomenon. An in-depth, longitudinal study of ESPP data since its inception is needed to quantify the “*perverted leaning*” [60] phenomenon, as both buyers and sellers got acquainted with the system and learned to properly (or, in our case, improperly) use it. Furthermore, fraud risk stemming from the repeated increases in the maximum allowed value for direct public e-procurement should be factored in, since these values doubled during 2022 and are currently more than tenfold higher than their initial levels in 2006, further enticing fraudulent behavior.

Given that fraud is not in any way localized and EU public procurement tends to become a level playing field, transversal research into similar EU e-markets is necessary in order to fully capture this phenomenon, and we call on the interested public or private entities to participate in furthering our research.

Furthermore, AI tools for real-time or ex-post fraud detection should be within reach of researchers and oversight bodies, provided that sufficient and adequate fraud case training data, such as criminal charges, complaints filed with relevant authorities, etc. [61], would

be made available, thus contributing to enhancing accountability and reaching sustainable development goals.

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## Appendix A

**Table A1.** Web-scraping robot for ESPP online direct acquisitions download.

Line No.	AutoIT V3 Instruction
1	<code>dim \$day = 0</code>
2	<code>dim \$month = 0</code>
3	<code>While \$month &lt;12</code>
4	<code>  \$month = \$month + 1</code>
5	<code>  \$day = 0</code>
6	<code>    While \$day &lt;31</code>
7	<code>      \$day = \$day+1</code>
8	<code>    Select</code>
9	<code>      case \$day &lt;10</code>
10	<code>        \$day1 = '0' &amp; \$day</code>
11	<code>        Select</code>
12	<code>          case \$month&lt;10</code>
13	<code>            \$month1 = '0' &amp; \$month</code>
14	<code>          case \$month &gt; 9</code>
15	<code>            \$month1 = \$month</code>
16	<code>        EndSelect</code>
17	<code>      case \$day&gt;9</code>
18	<code>        \$day1 = \$day</code>
19	<code>        Select</code>
20	<code>          case \$month&lt;10</code>
21	<code>            \$month1 = '0' &amp; \$month</code>
22	<code>          case \$month &gt; 9</code>
23	<code>            \$month1 = \$month</code>
24	<code>        EndSelect</code>
25	<code>    EndSelect</code>
26	<code>    \$date = \$day1 &amp; '/' &amp; \$month1 &amp; '/' &amp; '2023'</code>
27	<code>    ClipPut(\$date)</code>
28	<code>    MouseMove('Left', 1555,350,3)</code>
29	<code>    Send ("^v")</code>
30	<code>    MouseMove('Left', 1787,351,3)</code>
31	<code>    Send ("^v")</code>
32	<code>    sleep(500)</code>
33	<code>    Send("{Enter}")</code>
34	<code>    sleep(500)</code>
35	<code>    \$page_state = PixelGetColor( 1860 , 463 )</code>

Table A1. Cont.

Line No.	AutoIT V3 Instruction
36	While \$page_state <> 4034779
37	Sleep (1000)
38	\$page_state = PixelGetColor( 1860 , 463 )
39	WEnd
40	\$exceeds2k = PixelGetColor( 1811 , 525)
41	if \$exceeds2k <> 15558473 Then
42	MouseClicked('Left', 1444,772,1)
43	sleep (200)
44	Send("{RIGHT}")
45	sleep (200)
46	Send(\$date)
47	sleep (200)
48	Send("{LEFT}")
49	Send("{Down}")
50	Else
51	MouseClicked('Left', 1847,524,1)
52	sleep (200)
53	MouseClicked('Left', 1849,605,1)
54	sleep(500)
55	\$page_state = PixelGetColor( 1860 , 463 )
56	While \$page_state <> 4034779
57	Sleep (1000)
58	\$page_state = PixelGetColor( 1860 , 463 )
59	WEnd
60	EndIf
61	WEnd
62	WEnd

Source: own design using AutoIT v3.

## References

- Nesti, L. The 2010 “agreement on mutual enforcement of debarment decisions” and its impact for the fight against fraud and corruption in public procurement. *J. Public Procure.* **2014**, *14*, 62–95. [CrossRef]
- Rustiarini, N.W.; Sutrisno, T.; Nurkholis, N.; Andayani, W. Why people commit public procurement fraud? The fraud diamond view. *J. Public Procure.* **2019**, *19*, 345–362. [CrossRef]
- Foss, M.C.; Bonacelli, M.B.M. Analyzing the legal environment for public procurement as a demand-side innovation policy measure. *J. Public Procure.* **2023**, *23*, 35–55. [CrossRef]
- Azmi, K.S.A.; Rahman, A.A.L.A. E-Procurement: A tool to mitigate public procurement fraud in Malaysia? *Electron. J. E-Gov.* **2015**, *13*, 150–160.
- Duguay, R.; Rauter, T.; Samuels, D. The Impact of Open Data on Public Procurement. *J. Account. Res.* **2023**, *61*, 1159–1224. [CrossRef]
- European Parliament. Official Journal of the European Union. Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on Public Procurement and Repealing Directive 2004/18/EC. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0024> (accessed on 20 February 2024).
- Bulgarian Public Procurement Agency. Available online: <https://app.eop.bg/today/reporting/search> (accessed on 20 February 2024).
- Electronic Public Procurement Bulletin of the Republic of Croatia. Available online: <https://eojn.nn.hr/Oglasnik/> (accessed on 20 February 2024).
- Centrale Nazionale per Gli Acquisti della PA. Available online: <https://www.acquistinretepa.it/opencms/opencms/index.html> (accessed on 20 February 2024).
- Slovenian Directorate for Public Procurement. Available online: [https://ejn.gov.si/ponudba/pages/aktualno/aktualna\\_javna\\_narocila.xhtml](https://ejn.gov.si/ponudba/pages/aktualno/aktualna_javna_narocila.xhtml) (accessed on 20 February 2024).
- Romanian National Agency for Public Procurement. Available online: <https://www.e-licitatie.ro/pub/direct-acquisitions/list/1> (accessed on 20 February 2024).
- Sampaio, A.; Figueiredo, P.; Loiola, E. Public Procurement in Brazil: Evidence of frauds using the Newcomb-Benford Law. *Cad. Gestão Pública Cid.* **2022**, *27*, 1–20.
- Lyra, M.S.; Pinheiro, F.L.; Bacao, F. Public Procurement Fraud Detection: A Review Using Network Analysis. In *Complex Networks & Their Applications X, Proceedings of the Tenth International Conference on Complex Networks and Their Applications COMPLEX NETWORKS 2021, Madrid, Spain, 30 November–2 December 2021*; Springer: Cham, Switzerland, 2021; Volume 1, pp. 116–129.

14. Potin, L.; Figueiredo, R.; Labatut, V.; Largeron, C. Pattern Mining for Anomaly Detection in Graphs: Application to Fraud in Public Procurement. In Proceedings of the European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases, Turin, Italy, 18–22 September 2023; Springer: Cham, Switzerland, 2023.
15. Velasco, R.B.; Carpanese, I.; Interian, R.; Paulo Neto, O.C.; Ribeiro, C.C. A decision support system for fraud detection in public procurement. *Int. Trans. Oper. Res.* **2021**, *28*, 27–47. [[CrossRef](#)]
16. Khan, N.I.; Bakar, H. Malaysian Government Officials Induced in Public Procurement Fraud through the Lens of Fraud Diamond Analysis. *Asian J. Account. Gov.* **2022**, *18*, 1–16.
17. Engel, E.; Jordán, F.; Rau, T.; Repetto, A. Audit threats and year-end spending by government agencies: Experimental evidence from Chile. *J. Public Procure.* **2023**, *23*, 100–124. [[CrossRef](#)]
18. Bergman, M.A. Auditing and compliance in public procurement—An empirical assessment. *J. Public Procure.* **2023**, *23*, 125–144. [[CrossRef](#)]
19. Viana, L.C.; Moreira, J.A.; Alves, P. State audit of public–private partnerships: Effects on transparency, auditor’s roles and impact on auditee’s reactions. *Financ. Account. Manag.* **2022**, *38*, 633–660. [[CrossRef](#)]
20. Deephouse, D.L.; Bundy, J.; Tost, L.P.; Suchman, M.C. Organizational legitimacy: Six key questions. In *The SAGE Handbook of Organizational Institutionalism*; SAGE Publications Ltd.: Thousand Oaks, CA, USA, 2017; Volume 4, pp. 27–54.
21. Salijeni, G.; Samsonova-Taddei, A.; Turley, S. Big Data and Changes in Audit Technology: Contemplating a Research Agenda. *Account. Bus. Res.* **2018**, *49*, 95–119. [[CrossRef](#)]
22. Eililfsen, A.; Kinserdal, F.; Messier, W.F.; McKee, T.E. An exploratory study into the use of audit data analytics on audit engagements. *Account. Horiz.* **2020**, *34*, 75–103. [[CrossRef](#)]
23. Matthews, D. *A History of Auditing: The Changing Audit Process in Britain from the Nineteenth Century to the Present Day*, 1st ed.; Routledge: London, UK, 2006.
24. Alles, M.G.; Gray, G.L. Incorporating big data in audits: Identifying inhibitors and a research agenda to address those inhibitors. *Int. J. Account. Inf. Syst.* **2016**, *22*, 44–59. [[CrossRef](#)]
25. Earley, C.E. Data analytics in auditing: Opportunities and challenges. *Bus. Horiz.* **2015**, *58*, 493–500. [[CrossRef](#)]
26. Stewart, T. Data analytics for financial-statement Audits. In *AICPA, Audit Analytics and Continuous Audit: Looking Toward the Future*; American Institute of Certified Public Accountants: Durham, NC, USA, 2015; Chapter 5.
27. Krieger, F.; Drews, P.; Velte, P. Explaining the (Non-)Adoption of Advanced Data Analytics in Auditing. A Process Theory. *Int. J. Account. Inf. Syst.* **2021**, *41*, 1–24. [[CrossRef](#)]
28. Pedrosa, I.; Costa, C.J.; Aparicio, M. Determinants adoption of computer-assisted auditing tools (CAATs). *Cogn. Technol. Work* **2020**, *22*, 565–583. [[CrossRef](#)]
29. Government of Romania—Open Data Portal. Available online: <https://data.gov.ro/> (accessed on 25 February 2024).
30. Gravili, G.; Benvenuto, M.; Avram, A.; Viola, C. The influence of the Digital Divide on Big data generation within supply chain management. *Int. J. Logist. Manag.* **2018**, *29*, 592–628. [[CrossRef](#)]
31. Inkpen, R.; Gauci, R.; Gibson, A. The Values of Open Data. *Area* **2020**, *53*, 240–246. [[CrossRef](#)]
32. Calzada, I. (Smart) Citizens from Data Providers to Decision-Makers? The Case Study of Barcelona. *Sustainability* **2018**, *10*, 3252. [[CrossRef](#)]
33. Romanian Ministry of Public Finance. Available online: [https://extranet.anaf.mfinante.gov.ro/anaf/extranet/EXECUTIEBUGETARA/alte\\_rapoarte/alte\\_rapoarte2](https://extranet.anaf.mfinante.gov.ro/anaf/extranet/EXECUTIEBUGETARA/alte_rapoarte/alte_rapoarte2) (accessed on 25 February 2024).
34. Khder, M.A. Web Scraping or Web Crawling: State of Art, Techniques, Approaches and Application. *Int. J. Adv. Soft Comput. Its Appl.* **2021**, *13*, 145–168. [[CrossRef](#)]
35. Glez-Peña, D.; Lourenço, A.; López-Fernández, H.; Reboiro-Jato, M.; Fdez-Riverola, F. Web scraping technologies in an API world. *Brief. Bioinform.* **2014**, *15*, 788–797. [[CrossRef](#)] [[PubMed](#)]
36. Dewson, R. *Beginning SQL Server 2008 for Developers: From Novice to Professional*, 1st ed.; Apress: New York, NY, USA, 2008.
37. Brownlee, J. *Data Preparation for Machine Learning: Data Cleaning, Feature Selection, and Data Transforms in Python*, 1st ed.; Machine Learning Mastery: Victoria, Australia, 2020.
38. Refaat, M. *Data Preparation for Data Mining Using SAS*; Elsevier: Amsterdam, The Netherlands, 2010.
39. Vela, L. *A Tool to Support Data Exploration and Preparation*; Scuola di Ingegneria Industriale e dell’Informazione: Milano, Italy, 2021.
40. Zhang, S.; Zhang, C.; Yang, Q. Data preparation for data mining. *Appl. Artif. Intell.* **2003**, *17*, 375–381. [[CrossRef](#)]
41. Etzold, T.; Argos, P. Transforming a set of biological flat file libraries to a fast access network. *Comput. Appl. Biosci.* **1993**, *9*, 59–64. [[PubMed](#)]
42. Olsen, D.; Hauser, K. Teaching Advanced SQL Skills: Text Bulk Loading. *J. Inf. Syst. Educ.* **2007**, *18*, 399.
43. Rahm, E.; Do, H.H. Data cleaning: Problems and current approaches. *IEEE Data Eng. Bull.* **2000**, *23*, 3–13.
44. Maletic, J.I.; Marcus, A. *Data Cleansing. Data Mining and Knowledge Discovery Handbook*; Springer: Berlin/Heidelberg, Germany, 2005.
45. Pyle, D. *Data Preparation for Data Mining*; Morgan Kaufmann: Burlington, MA, USA, 1999.
46. Gao, J.; Xie, C.; Tao, C. Big data validation and quality assurance—issues, challenges, and needs. In Proceedings of the 2016 IEEE Symposium on Service-Oriented System Engineering (SOSE), Oxford, UK, 29 March–2 April 2016; pp. 433–441.
47. Bonter, D.N.; Cooper, C.B. Data validation in citizen science: A case study from Project FeederWatch. *Front. Ecol. Environ.* **2012**, *10*, 305–307. [[CrossRef](#)]

48. Horn, W.; Miksch, S.; Egghart, G.; Popow, C.; Paky, F. Effective data validation of high-frequency data: Time-point-, time-interval-, and trend-based methods. *Comput. Biol. Med.* **1997**, *27*, 389–409. [[CrossRef](#)] [[PubMed](#)]
49. The Romanian National Bank. Available online: <https://cursbnr.nxm.ro/#:~:text=Cursul%20mediu%20istoric,97379%20lei%20pentru%201%20euro> (accessed on 20 February 2024).
50. Sanda, M.R.; Trincu-Drăgușin, C.P. Supreme Audit Institutions and the Strive Towards an Open Data Culture. *Ovidius Univ. Ann. Econ. Sci. Ser.* **2021**, *2*, 1120–1130. [[CrossRef](#)]
51. Concilio, G.; Francesco, M. The Unexploitable Smartness of Open Data. *Sustainability* **2021**, *13*, 8239. [[CrossRef](#)]
52. Modrušan, N.; Rabuzin, K.; Mršić, L. Review of Public Procurement Fraud Detection Techniques Powered by Emerging Technologies. *Int. J. Adv. Comput. Sci. Appl.* **2021**, *12*, 1–9. [[CrossRef](#)]
53. Aristotelis, M.; Folinis, D.; Skiadas, D.; Xanthopoulos, A. Emerging Technologies Revolutionising Public Procurement: Insights from Comprehensive Bibliometric Analysis. *Adm. Sci.* **2024**, *14*, 23. [[CrossRef](#)]
54. Nai, R.; Sulis, E.; Meo, R. Public procurement fraud detection and artificial intelligence techniques: A literature review. In Proceedings of the 23rd International Conference on Knowledge Engineering and Knowledge Management, Bozen-Bolzano, Italy, 26–29 September 2022; pp. 1–13.
55. Torres Berru, Y.; López Batista, V.F.; Torres-Carrión, P.; Jimenez, M.G. Artificial intelligence techniques to detect and prevent corruption in procurement: A systematic literature review. In Proceedings of the Applied Technologies: First International Conference, ICAT 2019, Quito, Ecuador, 3–5 December 2019; Springer: Cham, Switzerland, 2019; Part II 1, pp. 254–268.
56. Neupane, A.; Soar, J.; Vaidya, K.; Yong, J. Role of public e-procurement technology to reduce corruption in government procurement. In Proceedings of the 5th International Public Procurement Conference (IPPC5), Seattle, WA, USA, 17–19 August 2012.
57. Zahra, F.; Abdullah, M.I.; Kahar, A.; Nurfalalah, N. Preventing Procurement Fraud in E-purchasing for Indonesian Local Governments. *J. Asian Financ. Econ. Bus.* **2021**, *8*, 505–511.
58. Huda, N.S.; Setiani, N.; Pulungan, R. Potential fraudulent behaviors in e-procurement implementation in Indonesia. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *185*, 012003. [[CrossRef](#)]
59. Popa, M. Uncovering the structure of public procurement transactions. *Bus. Politics* **2019**, *3*, 351–384. [[CrossRef](#)]
60. Van Thiel, S.; Leeuw, F.L. The performance paradox in the public sector. *Public Perform. Manag. Rev.* **2002**, *25*, 267–281. [[CrossRef](#)]
61. Niessen, M.E.K.; Paciello, J.M.; Fernandez, J.I.P. Anomaly Detection in Public Procurements using the Open Contracting Data Standard. In Proceedings of the Seventh International Conference on eDemocracy & eGovernment (ICEDEG), Buenos Aires, Argentina, 22–24 April 2020; pp. 127–134.

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