

Original Article

Econometric Analysis of Precious Metal Scrap Imports: VAR Model

Kazuka Nambu

School of Social Informatics, Aoyama Gakuin University

Abstract: Precious metals such as gold and platinum, which are essential for manufacturing, are essential resources that support Japan's industries. In the recovery of precious metals, primary resources such as mineral resources and secondary resources such as scrap are utilized. This paper considers precious metal scrap and electrical and electronic scrap as secondary resources. The purpose of this paper is to quantitatively show the interrelationships among four variables -- precious metal scrap, electrical and electronic scrap, copper concentrates, and industrial production. First, the analysis results show that precious metal scrap and electrical and electronic scrap have an asymmetric interrelationship. Second, the explanatory factors of shocks to electrical and electronic scrap are found to be different in the short run and long run. Finally, it is shown that the impact of precious metal scrap and industrial production should be taken into account in forecasting imports of electrical and electronic scrap.

Keywords: precious metal scrap, electrical and electronic scrap, copper ore, resources, VAR model

1. Introduction

Securing precious metals such as gold, silver, and platinum has become an urgent issue because Japan is poor in mineral resources, and precious metals are indispensable production elements in the manufacturing industry¹. For mineral resources such as gold, silver, and platinum, supply and demand are controlled on the supply side due to the uneven distribution of producing countries. On the other hand, scrap, a secondary resource,

is a resource for which a specific supply can be expected because all countries and regions using electrical and electronic equipment are potential sources of scrap supply. In addition, scrap resources have a high utilization value because their resource content is higher than

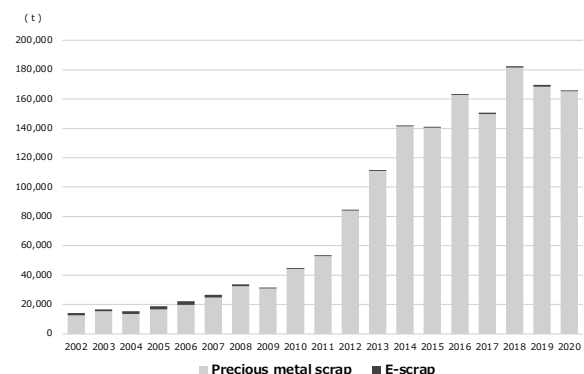


Figure 1: Trends in imports of precious metal scrap and electrical and electronic equipment scrap

¹ Precious metals include gold, silver, and platinum group metals which include platinum, palladium, rhodium, iridium, osmium, and ruthenium.

that of mineral resources themselves.

Figure 1 shows the recent trends in the import volume of precious metal scrap and electronics scrap. HS code 7112² of the trade statistics is used for precious metal scrap, and HS code 8548.90³ is for electronic equipment scrap. From the graph, we can see that there has been a particularly significant increase in the import of precious metal scrap, which has remained at about 160,000 tons for the past several years. About 93% of the precious metals scrap is silver-containing scrap, platinum-containing scrap is about 4%, and ash and gold-containing scrap are about 1.5% each.

The import volume of gold and platinum scrap is less in weight than that of silver-containing scrap. However, Okabe (2018) stated that gold has the largest market size. According to the Survey of Precious Metals Distribution, Japan's supply of gold and platinum will be about 159 tons and 2.7 tons, respectively, in 2020. In comparison, the supply of silver is 4,816 tons in the Non-Ferrous Metal Supply and Demand Statistics.

2 HS code 7112: Waste and scrap of precious metal or of metal clad with precious metal; other waste and scrap containing precious metal or precious metal compounds, of a kind used principally for the recovery of precious metal other than goods of heading 85.49.

--7112.30: Ash containing precious metal or precious metal compounds

--7112.91: Others of gold, including metal clad with gold but excluding sweepings containing other precious metals

--7112.92: Others of platinum, including metal clad with platinum but excluding sweepings containing other precious metals

--7112.99: Others

3 HS code 8548.90: Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators; electrical parts of machinery or apparatus, not specified or included elsewhere in this Chapter

-- 8548.10: Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators

-- 8548.90: Others

Regarding trading prices for precious metals, gold is 7,484 yen per gram, platinum is 4,222 yen per gram, and silver is 100.98 yen per gram⁴. Thus, the market size for gold is about 1.2 trillion yen, for platinum 11.2 billion yen, and for silver 486.4 billion yen. Considering that the price of gold around 2010 was about 3,500 yen per gram, it is clear that importing gold-containing scrap as a secondary resource is also an essential route to securing resources.

From January 2022, the new HS code 8549, which stands for electrical and electronic waste and scrap, will be available for use. This is due to the revision of the Import and Export Statistics Item List in accordance with the implementation of the revision of the HS Convention (HS2022 revision) on January 1, 2022. Within HS Code 8549, 8549.21, and 8549.29 include types of material used primarily to recover precious metals⁵. The term "scrap electrical and electronic equipment" includes materials suitable only for recovery, recycling, or disposal and does not include materials suitable for repair, reconstruction, reuse, or alteration. Therefore, the term "used equipment" is not the same as "scrap electrical and electronic equipment. This change in the HS code reflects the current trade situation and the growing global social concern about the trade in electrical and electronic scrap.

A great deal of research has been accumulated on the scrap generation mechanism, international trade, and recycling of individual materials such as aluminum,

4 As of January 20, 2022, Tanaka Kikinzoku Holdings, Inc.

5 HS code 8549: Electrical and electronic waste and scrap
-- 8549.21: Containing primary cells, primary batteries, electric accumulators, mercury-switches, glass from cathode-ray tubes or other activated glass, or electrical or electronic components containing cadmium, mercury, lead or polychlorinated biphenyls (PCBs)

-- 8549.29: Others

nickel, copper, and iron through economic analysis and actual surveys. Regarding the trade structure of metal scrap, which has become increasingly complex in recent years, some studies have attempted to clarify its structure. For example, Hu et al. (2020) describe the formation of three global communities, a hierarchical trade structure, and the monopolization of the export side. In addition, in recent years, many studies have analyzed the impact of China's waste and scrap import control policies, which began in earnest in 2017 (Tian et al. (2021)). Thus, while many studies on metal scrap include economic analysis, studies on precious metal scrap, such as gold, silver, and platinum, tend to be from an engineering perspective and rarely include economic analysis.

Another factor, which has not been incorporated in this paper but is likely to influence trade, is the change in precious metal content over time. In this point, Charles et al. (2017) analyzed DRAM, a high-grade waste material, and showed that if changes in precious metal content over time were not taken into account, there would be significant discrepancies in the prediction for recyclability.

Regarding the situation in Japan, Terazono et al. (2018) quantified the cross-border movement of recycled resources through case studies and summarized the trends in the import and export of precious metal scrap. In addition, as mentioned earlier, there are many previous studies on the recycling of precious metal scrap using an engineering approach with a focus on recycling technology. Okabe (2019) is a literature that provides an easy-to-understand explanation of smelting, refining, and recycling in Japan.

Since the trade of precious metal scrap is influenced by economic factors such as

the uneven distribution of primary resource exporting countries, resource prices, and competing demands for precious metal scrap, this paper will attempt to analyze it from an economic perspective. This study uses a VAR model to investigate the relationship between imports of recycled resources such as precious metal scrap and electronics scrap and imports of primary resources such as copper ore and copper ores and concentrates. In recent years, the demand for scrap resources has been rising, and fierce competition for resources has been raging. Thus, supply-side shocks could make resource competition increasingly severe. The purpose of this study is to examine the spillover effects among production factors in the event of some shocks on the supply side.

The following section describes the variables and data used and the unit root test and lag selection in section 3. Section 4 presents the results of the Granger causality test and the impulse response function based on the estimation of the VAR model, and finally, conclusions and remaining issues are discussed.

2. Variables and Data

The variables we use in this paper are precious metal scrap, electronic equipment scrap, copper ores and concentrates, and the index of industrial production. These four variables are denoted as PMSCRAP, ESCRAP, ORE, and IIP, respectively. This study focuses on the substitution and complementary relationship between precious metal scrap, electrical and electronic scrap, and copper ore and concentrates. PMSCRAP, ESCRAP, and ORE have been selected for this reason.

Table 1. Descriptive statistics

	Mean	Median	Minimum	Maximum	Std. Dev.	C.V.	Skewness	Ex.kurtosis
PMSCRAP	9.0911	9.3461	7.7358	9.7646	0.56522	0.062173	-0.93325	-0.4838
ESCRAP	4.1589	4.1682	3.1046	4.6766	0.29808	0.071673	-0.72304	0.78558
ORE	12.921	12.943	12.022	13.258	0.17555	0.013586	-1.1896	3.904
IIP	99.39	100.1	71.5	115.9	7.2096	0.072539	-0.81629	1.5817

Note) Std. Dev. is standard deviation and C.V. is coefficient of variation.

The remaining variable, IIP, has been based on gold and platinum uses. In 2020, approximately 68.6% of consumer demand for gold was for telecommunications equipment and machinery components. And of consumer demand for platinum, about 55.5% was for electrical and electronic equipment and about 15.5% for automotive catalysts. In short, since gold and platinum are considered to be essential materials for manufacturing, we use the industrial production index as another variable. As for other factors affecting this trade, the price of precious metals such as gold, silver, and platinum could be used as a variable, but due to the limitations of the VAR model, it is not used in this study.

The data of imports on precious metal scrap, electronic equipment scrap, and copper concentrates are from the Trade Statistics of Japan. The HS code for precious metal scrap is 7112, for electronic equipment scrap is 8548.90, and for copper ores and concentrates is 2603⁶. As for the Index of industrial production, it is from the Indices of Industrial Production of the Ministry of Economy, Trade and Industry. All data are monthly data from April 2009 to December 2020. Data for precious metal scrap, electronics scrap, and copper concentrates are logarithmic, and the base year for the industrial production index is 2015.

Table 1 shows the descriptive statistics of

the data used.

3. Unit root test and lag selection

We conducted the Augmented Dickey-Fuller test (ADF test) for four variables with 14 lags (Table 2). The null hypothesis that each data has a unit root is rejected at the 10% significance level for PMSCRAP, at the 5% significance level for ESCRAP, and at the 1% significance level for ORE and IIP. Therefore, all data used in this study will be considered to satisfy stationarity and used in the analysis at that level.

Regarding lag selection for the VAR model, the AIC, BIC, and HQ each showed three lags (Table 3). We will follow this result and choose lag three. In addition, the null hypothesis that the longest lag was 1 or 2 was rejected at the 1% significance level in VAR system estimation. On the other hand, the null hypothesis that the longest lag is 3 could not be rejected at the 5% significance level⁷.

Table 2. ADF test

	Level	
	test with constant	with constant and trend
PMSCRAP	-2.702 *	-0.981
ESCRAP	-2.971 **	-3.766 **
ORE	-6.851 ***	-6.847 ***
IIP	-4.003 ***	-3.589 **

Note) *, **, *** respectively indicate $p < .1$, $p < .05$ and $p < .01$.

6 HS code 2603: Copper ores and concentrates

7 Likelihood ratio test: Chi-square(16) = 25.4284, $p = 0.0626$

Table 3. Lag selection

lags	AIC	BIC	HQC
1	4.291	4.709	4.461
2	4.081	4.834	4.387
3	3.620 *	4.707 *	4.062 *
4	3.666	5.088	4.244
5	3.656	5.413	4.370
6	3.627	5.719	4.477

4. Estimation results

In this section, we estimate the four-variable VAR model with three lags and present the results of Granger's causality test, impulse response function, and variance decomposition.

4.1 Granger causality

The Granger causality test is a statistical hypothesis test to determine if one time series is useful in predicting another. Table 4 shows the results of the Granger causality test. For example, ORE→PMSCRAP indicates that there is Granger causality at the 5% significance level. Similarly, it can be said that ESCRAP has Granger causal with respect to PMSCRAP, ORE, and IIP as well as its own variables. With respect to IIP, it also has Granger causality with ESCRAP and ORE, as well as its own variables. Moreover, no Granger causality was found for ORE. Therefore, it cannot be said that the time series of other variables have a significant impact on the forecast of copper ores and concentrates imports. In the first place, Japanese non-ferrous metal smelting companies also invest in copper mines to secure a stable supply of raw materials regardless of trends in recycled resources, so it is quite possible that ORE is not affected by

Table 4. Granger causality

		F
PMSCRAP →	PMSCRAP	298.210 ***
ESCRAP →	PMSCRAP	1.920
ORE →	PMSCRAP	2.905 **
IIP →	PMSCRAP	0.307
PMSCRAP →	ESCRAP	3.307 **
ESCRAP →	ESCRAP	21.292 ***
ORE →	ESCRAP	3.022 **
IIP →	ESCRAP	3.457 **
PMSCRAP →	ORE	0.696
ESCRAP →	ORE	0.860
ORE →	ORE	0.368
IIP →	ORE	0.284
PMSCRAP →	IIP	0.233
ESCRAP →	IIP	3.832 **
ORE →	IIP	2.439 *
IIP →	IIP	24.682 ***

Note) *, **, *** respectively indicate $p < .1$, $p < .05$ and $p < .01$.

the time series of recycled resources.

4.2 Impulse response

Figure 2 shows the results of the impulse response function, a method of analyzing how a shock to one variable affects another variable. All variables show a tendency to fluctuate until around the 5th period and then converge. However, if we compare ORE→PMSCRAP and ORE→ESCRAP, we can see that PMSCRAP converges earlier. As for PMSCRAP→ESCRAP, the positive impact remains even in the 24th period, indicating that the impact of the shock may be prolonged. The impact of IIP→PMSCRAP is not clear, but the positive impact of IIP→ESCRAP is shown to be longer-lasting. In response to the shock to industrial production, imports of electrical and electronic scrap have increased, and the trend may continue.

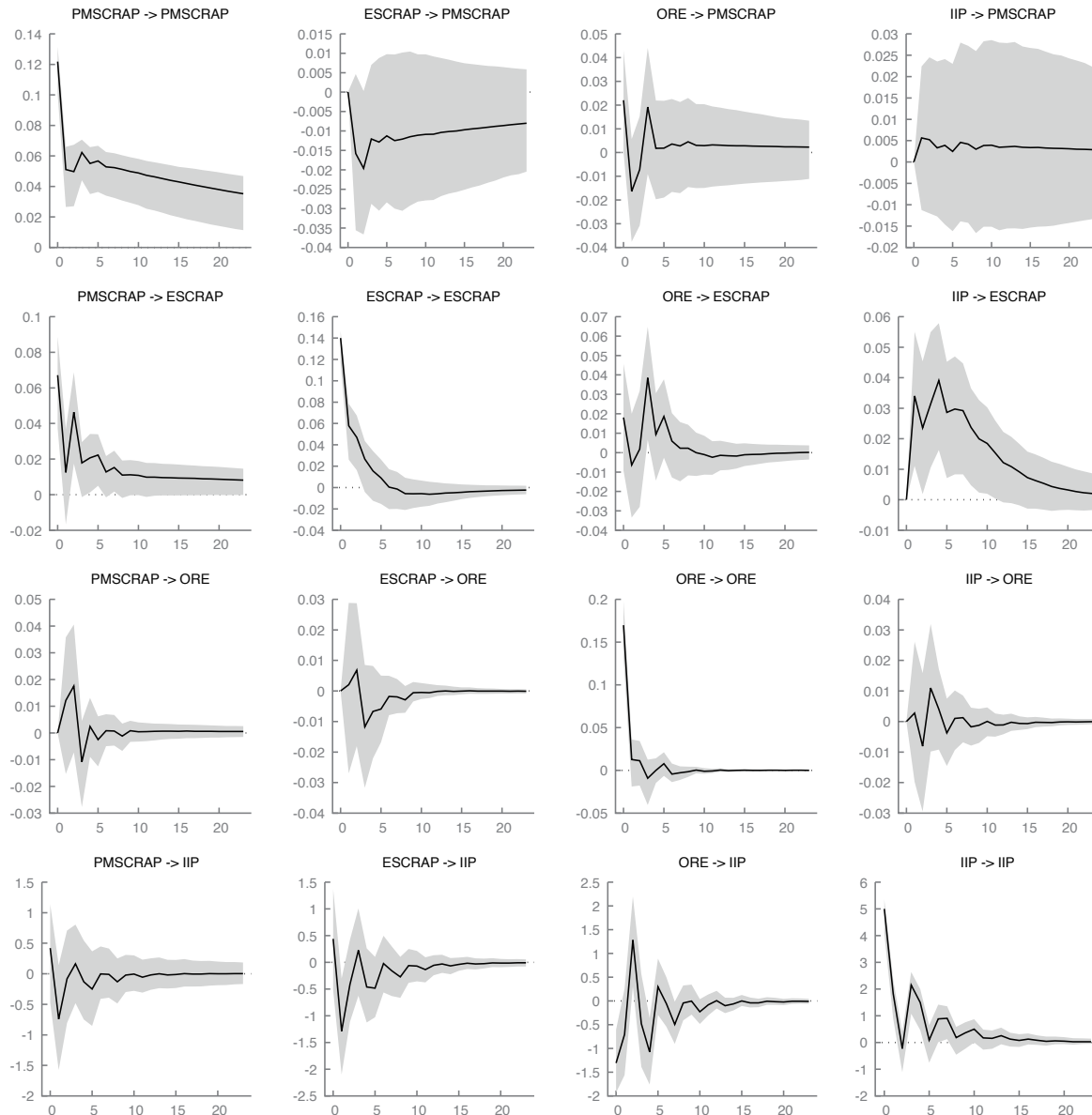


Figure2. Results of impulse response function

4.3 Variance decomposition

The results of variance decomposition are presented in Table 5. Variance decomposition is a method of analyzing which variables contribute how much to the variation caused by a given shock to a variable. Using variance decomposition, we can see the interrelationships among variables in more detail. In the short run, most of the impact of any variable is explained by its own shocks, but as the lag lengthens, the shocks of other variables may become higher.

The results in this paper are also explained mainly by own shocks in the short run. In the long run, the variance decomposition of ESCRAP shows a characteristic trend. Initially, it was about 80 percent, but in the 8th period, own shock is less than 60%, and it becomes about 55% in the long run. On the other hand, PMSRAP has been hovering around 20% throughout the period, and the IIP increases from 3.97% to about 18%. This means that electrical and electronic scrap will be affected by another recycled resource and the demand side of electrical and electronic scrap. This

is a feature not found in the PMSCRAP. The variance decomposition of the IIP showed that ORE shocks explain about 12% of the total variance, indicating some contribution from primary resources.

5. Conclusion

In utilizing secondary resources as one of the raw materials for resource recovery, it is crucial to clarify the relationship between copper ores and concentrates as a primary resource, precious metal scrap, and electrical and electronic scrap to secure resources for Japan.

The purpose of this study was not to look at the exact substitution and complementary relationships but to quantitatively measure whether these factors can explain the respective import volumes and how the shocks spillover.

The impulse response functions showed that although shocks to copper ores and concentrates caused fluctuations in precious metal scrap and electrical and electronic scrap, the shocks converged in about six months. It also showed a tendency for the precious metal scrap to converge more quickly. Regarding the relationship between recyclable resources, it was found that electrical and electronic scrap was statistically explained by the time series of precious metal scrap, but not the other way around. Since electrical and electronic scrap is explained not only by the time series of precious metal scrap but also by the time series of industrial production and copper ores and concentrates, it will be necessary to pay attention to the trends of manufacturing and primary resources as well as precious metal scrap

when forecasting electrical and electronic scrap.

The variance decomposition showed results for electrical and electronic scrap. The contribution of precious metal scrap was about 20% in both the short and long run, and the industrial production index made a more considerable contribution of about 20% in the long run compared to the short run. It can be seen that in the short run, there is the impact of imports of other recyclable resources. In the long run, there is the added impact of other recyclable resources and the demand side of recyclable resources. The analysis results in this paper show that after about 12 months, other factors will explain 40% of the shocks in electrical and electronic scrap. On the other hand, precious metal scrap and copper ores and concentrates are explained mainly by their own shocks, both in the short and long run.

Although trade statistics show that electrical and electronic scrap imports are smaller than those of precious metal scrap, it remains an essential recycling resource. It will be important to understand that only about half of the variation in electrical and electronic scrap can be explained by its own shocks in the long run. The analysis in this paper has quantitatively shown that the interrelationships among recyclable resources are not contrasting, and also the factors affecting them differ in the short run and long run. We believe that this will make a certain contribution to the consideration of resource security in Japan.

For the substitution and complementary relationships estimation, the estimation of simultaneous equation models can be considered. In addition, it is a future task to analyze how changes in resource prices affect trade in precious metal scrap and how the impact of price changes can be characterized in each upward and downward phase.

Table 5. Variance decomposition

Decomposition of variance for PMSCRAP						Decomposition of variance for ESCRAP					
period	std.error	PMSCRAP	ESCRAP	ORE	IIP	period	std.error	PMSCRAP	ESCRAP	ORE	IIP
1	0.124	96.835	0.000	3.165	0.000	1	0.156	18.444	80.211	1.345	0.000
2	0.136	94.403	1.351	4.075	0.172	2	0.171	16.005	78.756	1.268	3.971
3	0.146	93.004	2.963	3.756	0.276	3	0.185	20.018	73.863	1.095	5.025
4	0.161	92.170	3.023	4.536	0.271	4	0.194	19.005	68.884	4.933	7.179
5	0.170	92.406	3.257	4.044	0.293	5	0.200	18.993	65.540	4.871	10.596
6	0.180	92.771	3.312	3.636	0.282	6	0.204	19.388	62.989	5.498	12.125
7	0.188	92.844	3.474	3.365	0.318	7	0.207	19.278	61.393	5.441	13.888
8	0.196	92.941	3.591	3.129	0.339	8	0.209	19.330	59.865	5.317	15.488
9	0.203	93.027	3.669	2.966	0.338	9	0.211	19.290	58.968	5.243	16.500
10	0.209	93.110	3.729	2.809	0.352	10	0.212	19.328	58.314	5.178	17.181
11	0.215	93.179	3.781	2.674	0.366	11	0.213	19.379	57.754	5.124	17.743
12	0.220	93.224	3.839	2.564	0.373	12	0.214	19.431	57.366	5.094	18.109
13	0.226	93.272	3.879	2.468	0.381	13	0.215	19.524	57.088	5.067	18.321
14	0.230	93.311	3.915	2.383	0.391	14	0.215	19.623	56.850	5.047	18.480
15	0.235	93.343	3.950	2.309	0.398	15	0.216	19.734	56.656	5.032	18.578
16	0.239	93.373	3.979	2.244	0.405	16	0.216	19.853	56.503	5.017	18.627
17	0.243	93.398	4.005	2.185	0.412	17	0.217	19.976	56.366	5.004	18.654
18	0.246	93.420	4.030	2.133	0.418	18	0.217	20.101	56.242	4.992	18.665
19	0.250	93.440	4.051	2.086	0.423	19	0.217	20.224	56.134	4.981	18.661
20	0.253	93.458	4.071	2.043	0.428	20	0.217	20.347	56.032	4.971	18.650
21	0.256	93.474	4.089	2.005	0.433	21	0.218	20.466	55.937	4.961	18.635
22	0.259	93.488	4.105	1.970	0.437	22	0.218	20.582	55.849	4.952	18.617
23	0.261	93.501	4.120	1.938	0.441	23	0.218	20.694	55.766	4.943	18.596
24	0.264	93.513	4.134	1.908	0.445	24	0.218	20.802	55.688	4.935	18.575

Decomposition of variance for ORE						Decomposition of variance for IIP					
period	std.error	PMSCRAP	ESCRAP	ORE	IIP	period	std.error	PMSCRAP	ESCRAP	ORE	IIP
1	0.170	0.000	0.000	100.000	0.000	1	5.202	0.652	0.711	6.294	92.343
2	0.171	0.509	0.014	99.450	0.026	2	5.752	2.194	5.582	6.660	85.564
3	0.172	1.536	0.170	98.050	0.245	3	5.912	2.095	5.773	11.005	81.127
4	0.174	1.900	0.624	96.834	0.642	4	6.316	1.903	5.188	10.220	82.689
5	0.174	1.916	0.772	96.618	0.694	5	6.596	1.785	5.245	12.030	80.940
6	0.174	1.929	0.886	96.448	0.738	6	6.625	1.910	5.730	12.124	80.236
7	0.174	1.930	0.896	96.435	0.741	7	6.684	1.877	5.631	11.918	80.575
8	0.174	1.930	0.907	96.417	0.745	8	6.765	1.832	5.552	12.165	80.451
9	0.174	1.934	0.935	96.376	0.755	9	6.775	1.865	5.697	12.136	80.303
10	0.174	1.936	0.936	96.368	0.760	10	6.784	1.860	5.688	12.100	80.351
11	0.174	1.937	0.937	96.367	0.760	11	6.807	1.848	5.661	12.132	80.359
12	0.174	1.937	0.938	96.361	0.764	12	6.811	1.852	5.694	12.130	80.323
13	0.174	1.938	0.938	96.356	0.768	13	6.813	1.852	5.697	12.123	80.327
14	0.174	1.940	0.938	96.354	0.769	14	6.819	1.849	5.690	12.125	80.336
15	0.174	1.941	0.938	96.351	0.770	15	6.821	1.849	5.696	12.127	80.328
16	0.174	1.943	0.938	96.348	0.771	16	6.821	1.849	5.699	12.125	80.327
17	0.174	1.944	0.938	96.347	0.772	17	6.822	1.848	5.697	12.124	80.331
18	0.174	1.945	0.938	96.345	0.772	18	6.823	1.848	5.698	12.125	80.329
19	0.174	1.947	0.938	96.344	0.772	19	6.823	1.848	5.699	12.124	80.329
20	0.174	1.948	0.938	96.342	0.772	20	6.824	1.848	5.699	12.124	80.330
21	0.174	1.949	0.938	96.341	0.772	21	6.824	1.848	5.699	12.124	80.330
22	0.174	1.950	0.938	96.340	0.773	22	6.824	1.848	5.699	12.124	80.330
23	0.174	1.951	0.938	96.339	0.773	23	6.824	1.848	5.699	12.124	80.330
24	0.174	1.952	0.938	96.338	0.773	24	6.824	1.848	5.699	12.124	80.330

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