GLOBAL DEVELOPMENT OF METROLOGY: CASE STUDY OF VACUUM

D. Pražák[1], L. Peksa[2], T. Gronych[2]
[1] Czech Metrology Institute, Brno, Czech Republic
[2] Charles University, Prague, Czech Republic
E-mail (corresponding author): dprazak@cmi.cz

Abstract − The objective of this paper is to contribute to the discussion concerning the economic and social needs of advanced metrology and the economic preconditions for it that recently appeared in the literature. According to the authors, such discussion needs a broader, global scope at one hand and simultaneously a focus on the specifics of the individual metrology branches at the other hand. The results of the study of the common metrology are not comparable to those of the study of one specific field (vacuum in this case).

Keywords scientometry, Metre Convention, Mutual Recognition Arrangement, vacuum metrology

1. INTRODUCTION

Scientific and technological development of nations can be evaluated in many ways: gross domestic product (GDP) per capita, production of the sophisticated industrial products or weapons, capacity for space flights or directly scientific results. Often, the classical scientometric (bibliometric) criteria are used for this [1]. However, none of the criteria is entirely ambidextrous, applicable for all. As any organised human activity needs measurement, an interesting criterion could be an evaluation of development of the metrology. Only recently a comparative study of the national metrology institutes (NMI) was performed [2] and discussed [3-6] in the literature.

The pioneering work [2] focused only on the European Union, while the global situation was not mentioned. Moreover, it discussed the common metrology (all the subfields together) while a more detailed insight into some specific area could be useful.

In contrast to [2] that deals with the "profit" from an advanced metrology; the authors of this paper aim at the "basis" for an advanced metrology. The question is – who has and needs the most advanced metrology? This paper will start with the common metrology in the world first and then turn to the specific field of the vacuum metrology.

2. KEY COMPARISON DATABASE AS A SOURCE OF RANKING CRITERIA

There is a very suitable source of data for ranking the countries according to their metrological development. It is the Key Comparison Database (KCDB) [7] of the Mutual Recognition Arrangement (MRA) of the International Committee for Weights and Measures (CIPM). MRA assures the mutual recognition of the national measurement standards and the issued calibration certificates of the signatory NMIs to prevent possible technical obstructions of trade.

Basis of the MRA consists of:

1. a system of the international comparisons stored in the KCDB,

2. a demonstration of a quality system of each NMI,

3. the mutual recognition of Calibration and Measurement Capabilities (CMC).

The number of entries in CMC was first utilised as a scientometric criterion in [2]. However, the number of the comparisons listed in the KCDB can be utilised for this as well (some related statistics can be found at [8]).

3. COMMON METROLOGY

3.1. Metre Convention

Currently (December 2010), the Metre Convention has 54 member states plus 32 associates, totally 86 entities [9]. Comparison of the GDP per capita versus GDP of 174 countries (members, associates and non-members of the Metre Convention) is in Fig. 1.
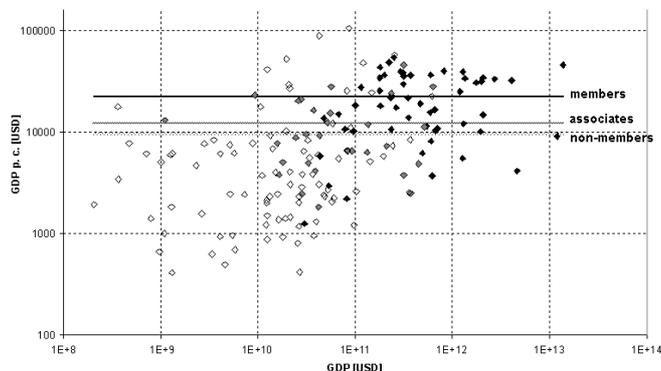

Fig. 1. Metre convention members (full diamonds), associates (grey diamonds) and non-members (empty diamonds) and their GDP per capita versus GDP

A strong correlation between wealth and development of a country and its degree of membership can be seen. The members have higher average GDP per capita (cca 22030 USD) then associates (cca 12140 USD) or non-members (cca 9440 USD).

3.2. Mutual Recognition Arrangement

Only the members (48 of 54, in December 2010) and associates (28 of 32, in December 2010) of the Metre Convention participate in the MRA [10]. (Additional three international organisations – members of the MRA – are not included in this study.)

The total number of the CMC entries of each country can be plotted versus population, GDP or GDP per capita as can be seen in Fig. 2 to 4.
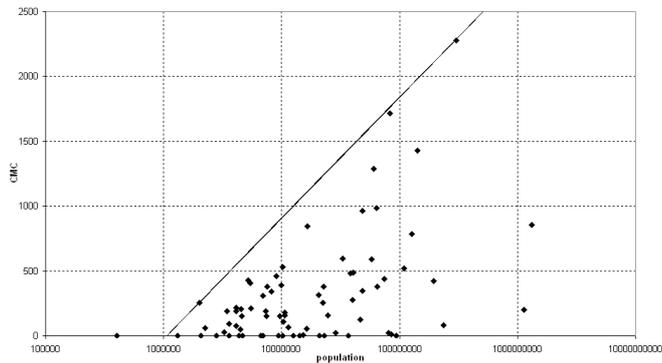

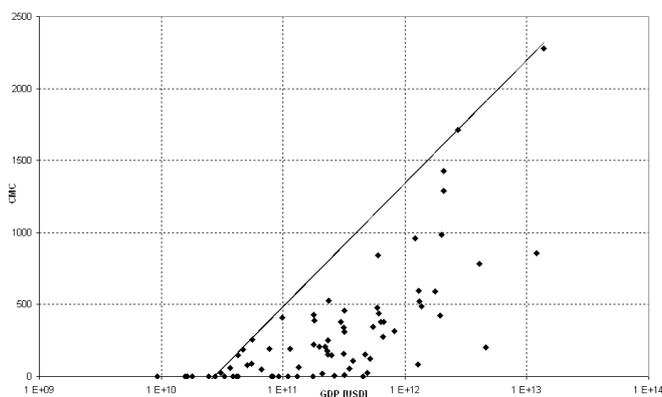Fig. 2. Total number of CMC entries versus population

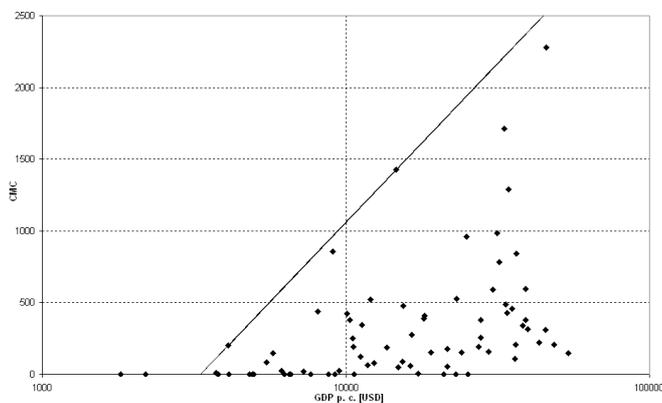Fig. 3. Total number of CMC entries versus GDP

Fig. 4. Total number of CMC entries versus GDP per capita

We can see very similar behaviour in all these graphs. First, a country must be above some strength limit to be able to have a non-zero number of the CMCs. Second, above that limit, there seems to be no correlation between strength of a country and the total number of its CMCs. Third, even the most agile countries cannot exceed a certain limit (black lines in Fig. 2 to 4) in this in dependence on their strength.

Similarly, the total number of the Key and Supplementary Comparisons (KCSC) of each country can be plotted versus the same variables (Fig. 5 to 7).
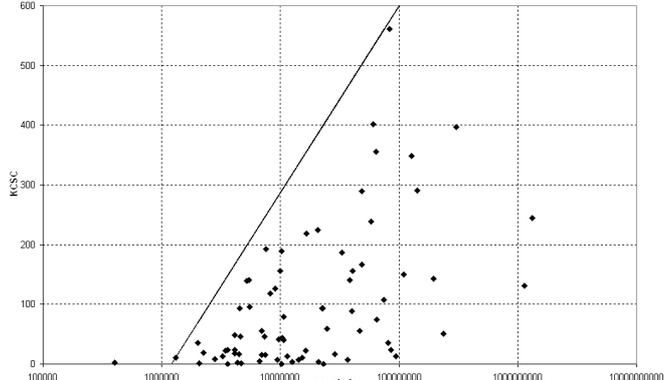

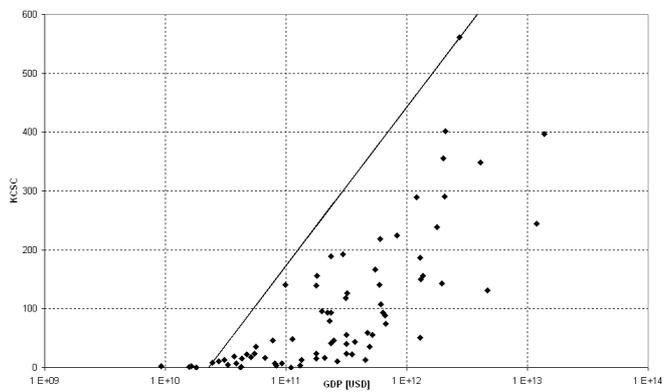Fig. 5. Total number of KCSCs versus population
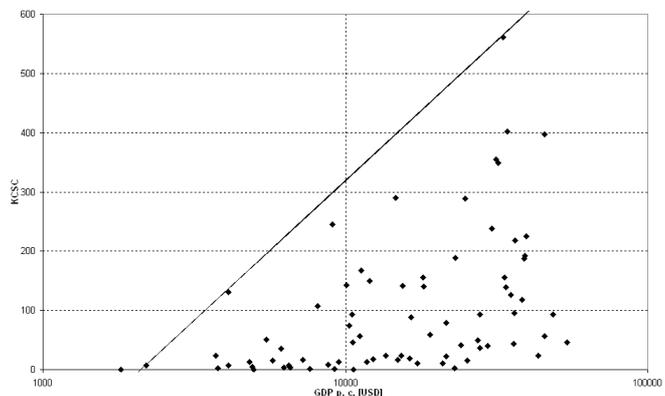

Fig. 6. Total number of KCSCs versus GDP

Fig. 7. Total number of KCSCs versus GDP per capita

The same as for Fig. 2 to 4 can be also said about Fig. 5 to 7. It can be explained by the fact that the number of the KCSC per one CMC entry does not vary much for the different countries. This number usually lies in the interval from 0.2 to 0.5. Only one fifth of the MRA members are exception from this.

Proceedings

2nd IMEKO TC 11 International Symposium METROLOGICAL INFRASTRUCTURE
June 15-17, 2011, Cavtat, Dubrovnik Riviera, Croatia

Limit of the total number of CMCs in dependence on the population π (for countries with π above cca 1100000):

$$L_{\pi} = 405 \cdot \ln(\pi) - 5620. \tag{1}$$

Limit of the total number of CMCs in dependence on the GDP α (for countries with α above cca $2.8 \cdot 10^{10}$ USD):

$$L_{\alpha} = 372 \cdot \ln(\alpha) - 8937. \tag{2}$$

Limit of the total number of CMCs in dependence on the GDP per capita κ (for countries with κ above cca 3350 USD):

$$L_{\kappa} = 962 \cdot \ln(\kappa) - 7800. \tag{3}$$

Limit of the total number of KCSCs in dependence on the population (for countries with π above cca 1300000):

$$\Lambda_{\pi} = 136 \cdot \ln(\pi) - 1905. \tag{4}$$

Limit of the total number of KCSCs in dependence on the GDP (for countries with α above cca $2.4 \cdot 10^{10}$ USD):

$$\Lambda_{\alpha} = 117 \cdot \ln(\alpha) - 2790. \tag{5}$$

Limit of the total number of KCSCs in dependence on the GDP per capita (for countries with κ above cca 2200 USD):

$$\Lambda_{\kappa} = 205 \cdot \ln(\kappa) - 1569. \tag{6}$$

Of course, the exact values of (1) to (6) are not important and (at least these for the number of comparisons) they will (hopefully) grow in the future. What is striking is the sole fact of existence of such limits. It tells us that although the agility of countries in metrology varies chaotically and independently of their power, their maximal success is clearly limited by it.

However, the criteria used up to now (number of CMCs or KCSCs) tell nothing about quality. A very precise calibration service can be present in CMCs as well as a less precise. A comparison is present in the KCDB no matter whether it was successful or not. A much more objective approach is needed, but the wide field of metrology prevents finding of a common criterion for it. Hence, there will be presented a detailed study of one definite branch – vacuum metrology.

4. VACUUM METROLOGY

4.1. General

Calibrations in the vacuum range (absolute pressures below 100 kPa) are not a common service. Only less then one half (41) of Metre Convention entities have CMCs in this range. And, in fact, many NMIs cover only the range of coarse vacuum and their ultimate covered pressures are only 10 kPa (or even 15 kPa). Only four NMIs go below the limit

of 1 μPa [11]. However, mostly the more developed countries maintain vacuum CMCs; their average GDP per capita is cca 39960 USD (compare with data in 3.1).

4.2. Searching a suitable criterion

However, a simple evaluation of ranking of the countries mentioned in 4.1 according to their capabilities in vacuum is complicated. The database consists of too much data; some countries provide only their best CMC for a certain range while others have for it several CMCs according to the type of the device to be calibrated.

Possible solution is to focus only on the lowest (ultimate) pressure covered by CMCs - p_u. There are plotted the relative expanded uncertainties $U_r(p_u)$ against p_u in Fig. 8. Two major groupings can be seen in it. The pressure balances working in absolute mode in the right bottom corner and the various expansion systems in the left upper corner.
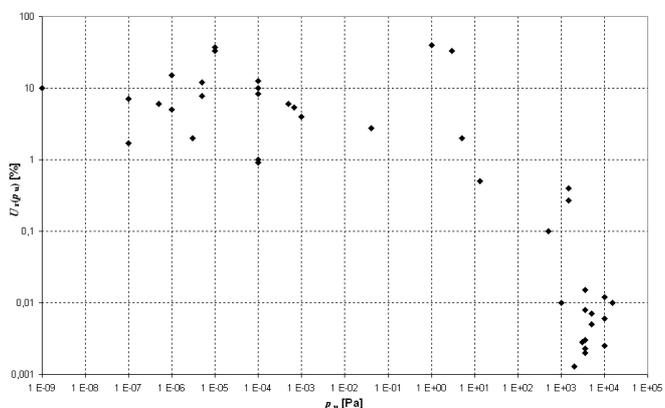

Fig. 8. Ultimate pressure versus its relative uncertainty

However, Fig. 8. shows that p_u is not a sufficient criterion for ranking NMIs in this field, because many of them declare the same p_u, but with very different $U_r(p_u)$. This leads to a suitable ranking criterion – absolute uncertainty of the ultimate pressure $U_a(p_u)$ – as can be seen in Fig. 9. The lower number is reached, the better vacuum capabilities the country has.
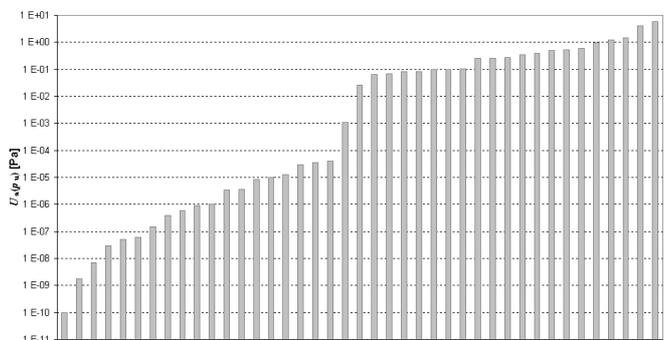

Fig. 9. Absolute uncertainty of the ultimate pressure as a ranking criterion

4.3. Searching a correlation

Having a ranking criterion, it can be easily plotted against population, GDP and GDP per capita as can be seen in Fig. 10 to 12.
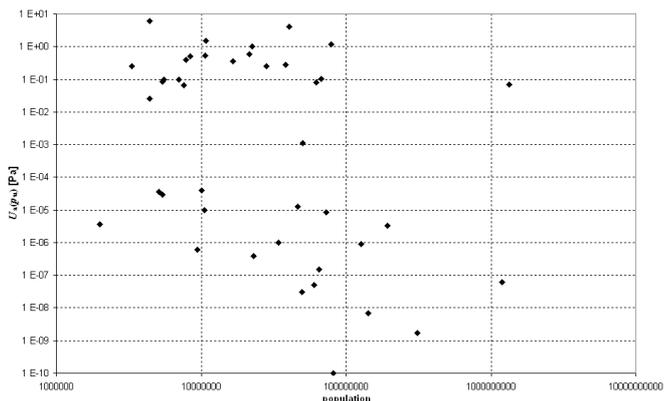
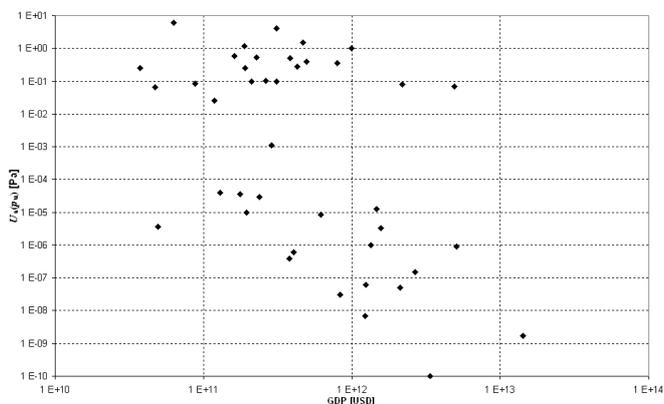Fig. 10. Absolute uncertainty of the ultimate pressure versus population

Fig. 11. Absolute uncertainty of the ultimate pressure versus GDP
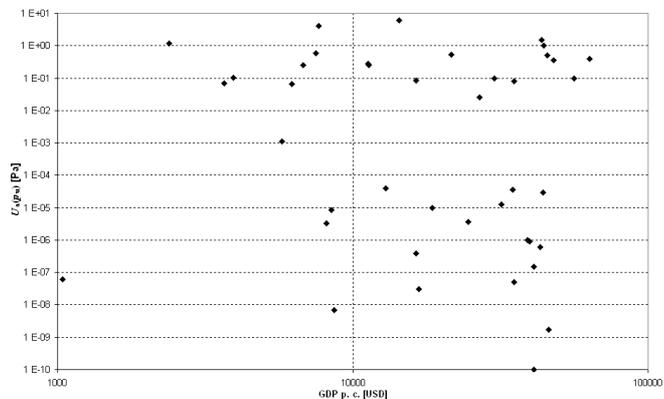

Fig. 12. Absolute uncertainty of the ultimate pressure versus GDP per capita

No correlation between power or development of a country and its vacuum calibration capabilities can be seen. There is only a simple grouping (with only one exception) into "active" and "passive" countries that are separated by two orders. However, some slight correlations occur in the "active group".

5. CONCLUSION

There is a striking contrast between the common metrology and a specialised branch. Whereas an ability of a country to support all fields of metrology is clearly limited by its power or development, there are absolutely no limits to excel in a specialised branch as e.g. vacuum. It probably coheres with contemporary globalised economy, where a centre of excellence in a small economy can offer its services abroad. Hence, the reasons for establishing a top metrology service in a particular quantity are probably given by human resources, possibilities of cooperation with academic or industrial sphere and (of course) tradition of a particular metrology branch in a particular country.

ACKNOWLEDGEMENTS

REFERENCES

[1] D. A. King: "The scientific impact of nations"; *Nature*, Vol.430, Issue 6997, 2004, p.p 311–316.
[2] N. Poposki, N. Majcen, P. Taylor: "Assessing publically financed metrology expenditure against economic parameters"; *Accreditation and Quality Assurance*, Vol.14, Issue 7, 2009, p.p 359–368.
[3] P. Klenovsky: "Comment on "Assessing publically financed metrology expenditure against economic parameters""; *Accreditation and Quality Assurance*, Vol.14, Issue 12, 2009, p.p 701.
[4] N. Poposki, N. Majcen, P. Taylor: "Authors' reply to the comment on "Assessing publically financed metrology expenditure against economic parameters""; *Accreditation and Quality Assurance*, Vol.14, Issue 12, 2009, p.p 703.
[5] G. Beges, J. Drnovsek, L. R. Pendrill: "Optimising calibration and measurement capabilities in terms of economics in conformity assessment"; *Accreditation and Quality Assurance*, Vol.15, Issue 3, 2010, p.p 147–154.
[6] G. Price: "Failures of the global measurement system. Part 1: the case of chemistry"; *Accreditation and Quality Assurance*, Vol.15, Issue 7, 2010, p.p 421–427.
[7] http://kcdb.bipm.org/
[8] http://kcdb.bipm.org/kcdb_statistics.asp
[9] http://www.bipm.org/en/convention/member_states/
[10] http://www.bipm.org/en/cipm-mra/participation/signatories.html
[11] L. Peksa, D. Pražák, T. Gronych, P. Řepa, M. Vičar, J. Tesař, Z. Krajíček, F. Staněk: "Primary Vacuum Standard for UHV Range - Standing Experience and Present Problems"; *MAPAN*, Vol.24, Issue 1, 2009, p.p 77–88.

Authors: Mgr. Dominik Pražák, Czech Metrology Institute, Okružní 31, 63800 Brno, Czech Republic, +420 545 555 226, +420 545 555 183, dprazak@cmi.cz.
RNDr. Ladislav Peksa, CSc., Charles University, V Holešovičkách 2, 18000 Praha 8, Czech Republic, +420 221 912 310, +420 284 685 095, peksa@mbox.troja.mff.cuni.cz.
RNDr. Tomáš Gronych, CSc., Charles University, V Holešovičkách 2, 18000 Praha 8, Czech Republic, +420 221 912 227, +420 284 685 095, gronych@mbox.troja.mff.cuni.cz.