EXPERT
REPORT

OIML E 7

Edition 2015 (E)

Modelling the economic impact of legal metrology

OIML E 7 Edition 2015 (E)

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
OF LEGAL METROLOGY

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CONTENTS

OIML Foreword 5

MODELLING THE ECONOMIC IMPACT OF LEGAL METROLOGY 6

Executive Summary 7

I) Legal metrology, Society and Trade 9

A history of social and economic benefits 9

The creation of an international network of metrology organisations 10

II) Identifying the economic and social benefits of metrological systems 12

Fundamental economic benefits in the literature 12

Benefits to international trade 13

Quantifying the benefits of legal metrology 15

The ISO methodology 16

III) Measuring the impact of legal metrology on growth 18

Legal metrology, standards and innovation 18

EMPIRICAL ESTIMATIONS USING THE STOCK OF STANDARDS 20

SPENDING IN METROLOGY AND AGGREGATE PRODUCTIVITY 22

IV) Guidelines for an econometric analysis at the macro level: 25

V) Lessons learned from sectorial case STUDIES 27

Benefits for producers 27

Benefits for consumers 33

Impact of Measurement methodology 34

VI) Modelling the microeconomic impact of measurement 35

Transaction costs 36

Productivity increase 38

Price increase 41

Social welfare 43

VII) Case studies: assessing the impact of the maximum permissible error requirements in the australian wheat, coal and sugar industries 45

Selecting an existing model as a starting point 45

Application to the Australian wheat, sugar and coal industries 50

Conclusion 56

Bibliography 57

Appendix: R code 59

OIML Foreword

The International Organization of Legal Metrology (OIML) is a worldwide, intergovernmental organization whose primary aim is to harmonize the regulations and metrological controls applied by the national metrological services, or related organizations, of its Member States. The main categories of OIML publications are:

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- **International Guides (OIML G),** which are also informative in nature and which are intended to give guidelines for the application of certain requirements to legal metrology;
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This publication, OIML E 7, edition 2015 (E) – was written by Yasmine Bekkouche and Caroline Jeangeorges, students of the Paris-based *National School of Statistics and Economic Administration* under the supervision of Dr. Valerie Villiere, the CIML Member for Australia.

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MODELLING THE ECONOMIC IMPACT OF LEGAL METROLOGY

This report, commissioned by the International Organization of Legal Metrology (OIML – *Organisation Internationale de Métrologie Légale*), is the result of the collaboration between the OIML and ENSAE Junior Etude (Yasmine Bekkouche and Caroline Jeangeorges*)*. Its purpose is to show how important the metrological standards, norms and recommendations of legal metrology are for producers, consumers and the economy and society at large. We begin by reviewing some of the literature on the economics of standards and legal metrology. The bulk of the report is then suggesting a model for assessing and quantifying the economic benefits of adopting legal metrology standards at the firm, sector and national levels.

If many studies and surveys describe these potential benefits, very few give a reproducible methodology to quantify precisely the impact of metrology on wealth and value creation. The difficulty is well known: in the absence of a counterfactual, identifying and modelling the effects of standard adoption or the return on investments in metrology is a complex matter. This report examines the literature on that topic (parts I to IV) – though not exhaustively – in order to determine the different elements to include in our model.

Guidelines for a macro econometric model are put forward, as well as benefits identified in microeconomic case studies (part V). A theoretical model is then put forward to analyse the benefits of legal metrology (part VI). Finally we will illustrate this report with a case study (part VII) evaluating the impact of legal metrology in three Australian sectors: wheat, sugar and coal. The OIML, through Dr. Valerie Villiere, has followed closely the different steps of the conception of the report. We would like to thank her and the OIML for their support. However, any mistakes and imprecisions remain of the authors' responsibility alone.

EXECUTIVE SUMMARY

The report begins with a literature review centred on the benefits scientific, industrial and legal metrologies have brought to societies since the 18th century. Works in history, economics and social sciences are used to understand the social and economic benefits associated with the construction of an international system of units followed by a global network of metrological organisations still expanding today.

Moving on to the specialized literature in economics of metrology and standards, Section II sums up the most generally accepted benefits of every metrology- and standard-related activity that might be of interest in order to appraise the gains brought by legal metrology itself. That includes benefits to international trade, which are to a large extent the product of international harmonization and cooperation in legal metrology. In conclusion of the literature review, we address the problem of quantifying the economic benefits of legal metrology by summarizing the different options available and presenting the ISO framework for identifying the assets in an organisation that legal metrology can be beneficial to.

The third section of the report examines how different measures of the activity of national metrology organisations are used in the literature to estimate the impact of metrology on growth and innovation. Those measures include: government spending metrology R&D, stock of standards, patents and publications and sector-specific advantages. The possibility of using similar indicators (proxies) for estimating the economic benefits of legal metrology is discussed, on the basis that standardisation and legal metrology activities such as conformity assessment involve the same actors and produce comparable benefits. Section III goes on reviewing a selection of studies on the impact of legal metrology and standardisation on innovation, aggregate productivity or labour productivity.

Section IV provides some methodological elements for building an econometric model at the macro level. Various explained variables for the model as well as proxies for legal metrology activity are discussed. A method is described for an analysis with an international scope.

Section V focuses on the microeconomic benefits of legal metrology underpinning the models presented in sections III and IV. Benefits for producers and consumers are identified in sectorial case studies selected in the literature. Such benefits include: reduced transaction costs (search and information, bargaining, enforcement); increased productivity; access to new markets; information, quality and price premium. On the consumers' side, advantages include: information, quality assurance, new products and network effects.

Section VI presents a theoretical model for for quantifying the gain brought by conformity to legal metrology requirements to the profits of producers. Drawing from the producer microeconomic theory, the proposed maximisation programme takes into account the effect of legal metrology in the objective function of the producer in order to augment its benefits.

Another model is put forward, to help determine to optimal amount of public investment in metrology and standardisation.

Section VII develops a method to quantify the effects of uniform maximum permissible errors (MPE) in trade. Impact study on the divergence of MPEs is a way to quantify the economic benefits of legal metrology. Indeed legal metrology is used to ensure smooth transaction in trade particularly by fixing MPEs. Two types of divergence of the MPEs between buyer and seller are examined. The first type is a small deviation in the MPEs that correspond to a translation of the testing limit of the measurement instrument. This translation leads to differences in the testing limit for the product traded. The second divergence considered is the situation where the MPEs are of different magnitudes. In this second case, an economic loss of 9,299,354 AUD over three industries is found for the hypothetical situation where the Australian MPEs would be twice higher than the international one.

I) LEGAL METROLOGY, SOCIETY AND TRADE

A HISTORY OF SOCIAL AND ECONOMIC BENEFITS

For over five millennia, societies have invented and refined means to measure time, weights, distances, frequencies, areas. Metrology, in its widest sense, is the science of measurement and it is safe to say that is has steadily brought benefits to the economies of all societies. By ensuring that the standards we use – ideas and objects we deem good benchmarks – have precise values that make them useful for comparison, metrology plays an essential role in our economic lives. As the literature on the history of metrology shows, the development of metrology systems and legal standards has been instrumental in the expansion of domestic and international trade. The need for consistent and reliable measurements is old: ancient metrological systems were based on the features of a sovereign (such as the arm length of the pharaoh in ancient Egypt), followed precepts in the holy books or royal decrees. With the expansions of cities, public infrastructure and manufactured goods, metrology became an increasingly important (but not always visible) part of everyday life.

The importance of accurate and transparent measurement grew again with the standards, laws and legal requirements brought by the consolidation of the State in the 18th and 19th centuries, as well as with the expansion of industry. In the last decades, following the rapid growth of international trade, metrology evolved toward the standardization of measurement units and methods in a globalized world. The literature on the development of metrology and its history is vast, but a good starting point would be the collective book edited by **(Wise 1997)**, exploring the rise of quantitative precision as a fundamental value of modern science and industry. Other valuable sources on the history of measurement include: **(Robinson 2007)** and **(Whitelaw 2007)**.

The origin of modern metrology is usually placed in the 18th century in France, with the introduction of the decimal metric system (1799), replacing the multitude of different units used for local trade. Another key element is of course the industrial revolution of 19th century Europe. The metric system became legal in Great Britain in 1864 and was adopted in Germany in 1868 (although the UK came short of adopting it, partly because of the powerful textile sector, reluctant of the immediate costs). In 1875, the Metre Convention (also known as the Treaty of the Metre) was signed in Paris by representatives of 17 nations and quickly grew to cover more countries (56 member states in 2014) and areas other than weights and measures, such as: electrical standards (1921), photometric standards (1927), ionizing radiation standards (1960s), time standards (1987), chemistry metrology (1993) and, finally, metrology in all scientific areas (1999).

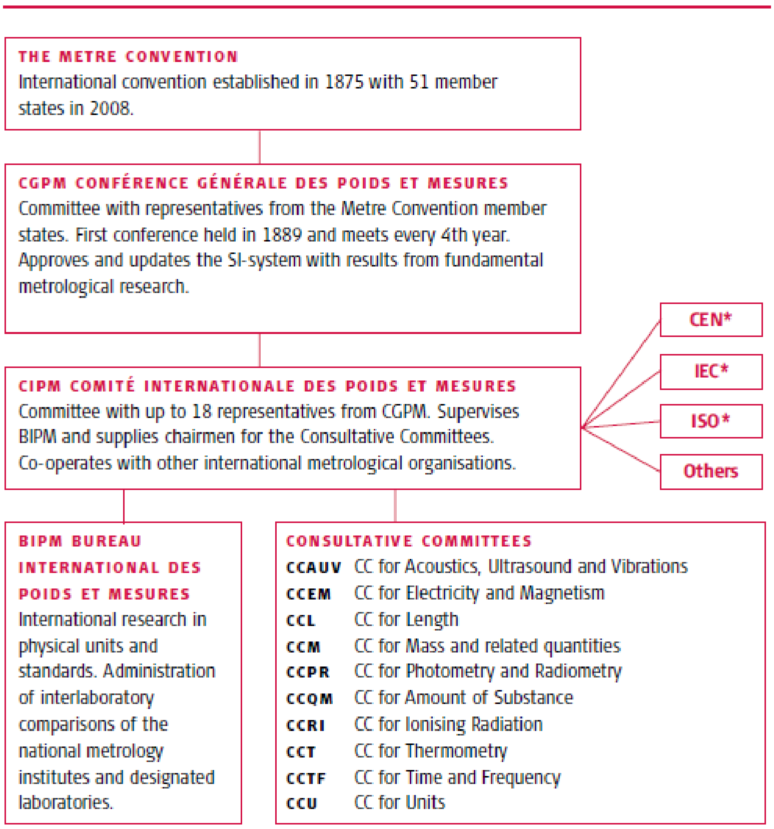
At the same time, as metrological activities grew in scope and volume, their classification evolved:

"One institutional aspect of the development of metrology in the 20th century was the separation of metrology in many countries into scientific metrology, led by the National Metrology Institutes, and practical or legal metrology, administered by weights and measures authorities" (Birch 2003).

THE CREATION OF AN INTERNATIONAL NETWORK OF METROLOGY ORGANISATIONS

The 1875 Convention also institutes the BIPM (*Bureau International des Poids et Mesures* or International Bureau of Weights and Measures), designed – after some controversy at the time[1] – as an international *scientific* organisation supported by member states for the purpose of carrying out *scientific* work related to metrology, instruments and units. This was, one might observe, a way to maintain metrology for science and metrology for Law and trade separate; the latter deserving perhaps more diplomatic attention since it influenced directly international trade and relations between member states.

Figure 2: The Metre Convention organisation



Source: (Howarth and Redgrave 2008)

Legal metrology has evolved to cover the "practice and process of applying statutory and regulatory structure and enforcement to metrology" (*i.e* measurement, units of measurement, measuring instruments and methods of measurement (OIML 2011).

[1] Cf. Quinn, 2005 p.2311

The BIPM was created along two other international institutions under the Metre Convention: the General Conference on Weights and Measures (*Conférence générale des poids et mesures*, CGPM) and the International Committee for Weights and Measures (*Comité international des poids et mesures*, CIPM). A number of National Metrology Institutes (NMI) was established in Europe in the following years. The *Physikalisch-Technische Reichsanstalt* (PTR), created in 1887 in Berlin, was the first national standards laboratory. In 1960, the International System of Units (SI system) replaced the original system of the Convention, but kept its fundamental units (Metre, Kilogram, Second, Ampere) and adding the Kelvin and the Candela.

We have seen that the development of metrology coincided with the emergence of modern science: an international network of scientists producing comparable and reproducible results, and that a branch of metrology specialised as such. But it is also is closely linked to the industrial revolutions of the 19th and 20th centuries and the development of manufacturing techniques for mass production. Indeed, as (Quinn and Kovalevsky 2005) put it:

> *"The rapid development of manufacturing technology during the first half of the nineteenth century was accompanied by, and in fact could hardly have taken place without, a corresponding development in the design and manufacture of measuring machines, standardization of screw threads and indeed such basic things as engineering flat surfaces and straight edges, all of which are essential for precision manufacturing on a large-scale."*

Aside from everyday life, science and industry, improvements in metrology provided important advantages to national and international trade. Aside from accompanying advances in production and quality, metrological developments were also historically designed to ensure fair trade. Indeed, the State, by safeguarding the quality of measuring instruments and the comparability of units, lowered the costs associated with disputes and technical barriers to trade (TBT). As we will see, this aspect has expanded to most trade operations and is still a critical function of legal metrology today, in the public as in the private sector. After all, trade depends on units of mass, length and volume at a fundamental level since their measurement determines the price. But the economic benefits of investing in metrology and standards are not limited to quantitative precision.

II) IDENTIFYING THE ECONOMIC AND SOCIAL BENEFITS OF METROLOGICAL SYSTEMS

FUNDAMENTAL ECONOMIC BENEFITS IN THE LITERATURE

As we have seen, metrology played a central role in the expansion of mass manufacturing. For many authors, it can thus be considered an essential requirement for an effective division of labour. Indeed, the division of labour depends on formal and informal norms and standards so as to make possible the optimal intervention of multiple agents on the same production chain. **(Barber 1987)** notes that a lack of widely accepted measurement standards results in higher transaction costs, meaning that companies will do things in-house rather than outsourcing tasks to more efficient specialists, hence losing the benefits of the division of labour.

The benefits of measurement innovation, combined to legal metrology standards, also show up as an increase in productivity. Various authors cite benefits to productivity stemming from the metrological added value to integrated process control [**(Dunn 2005)** and **(Johnson 2006)**], reduced costs of meeting regulation or better decision-making **(Swann 2009), p.46-47**). But the oldest beneficial effect of improved measurement standards on productivity to have been identified is certainly the production of interchangeable parts. Thomas Jefferson observed this in 1875 when visiting France:

> *"An improvement is made here in the construction of muskets, which it may be interesting to Congress to know …. It consists in the making every part of them so exactly alike, that what belongs to any one, may be used for every other musket in the magazine … I put several together myself, taking pieces at hazard as they came to hand, and they fitted in the most perfect manner. The advantage of this when arms need repair are evident. He effects it by tools of his own contrivance, which, at the same time, abridge the work, so that he thinks he shall be able to furnish the musket two livres cheaper than the common price"*

By reducing the barriers to entry and representing the interests of producers, consumers and other stakeholders, open standards are also thought to increase competition **(Swann 2009)**. By promoting new entrants and increasing competitive pressure on incumbent companies, metrological standards also foster innovation. As P. Swann also notes, widely accepted metrological standards also help innovative companies prove the benefits of new products by providing recognized standards for consumers to compare to. Indeed:

> *"If the innovator cannot achieve a premium for his innovations, then the economic incentive for innovation may be lost."*[2]

[2] *Ibid, p. 47*

Many authors have underlined the importance of trust in economic transactions – indeed; the entire economic circuit is based on some level of trust between agents. A substantial part of that vital element of trade is provided by an international network of certifications and standards, in turn relying on metrology organisations and metrological systems. In economic terms, metrology – and legal metrology in particular – mitigates the effects of information asymmetry. If the seller knows more about the product being sold than does the buyer, the lack of trust in the transaction can lead to dramatic market failures, such as honest sellers being driven out of the market. This is reminiscent of Gresham's Law: when the "real" value of a commodity shows a significant difference with the value people are required to accept, "bad products" will drive out "good products". This information asymmetry problem was famously illustrated in **(Akerlof 1970),** in an article about lemons on the second-hand car market. By ensuring that buyers and sellers both benefit from reliable metrological information, as well as requiring that sellers are submitted to relevant standard comparisons, legal metrology mitigates that risk. Also, standards can be considered as a form of technology infrastructure that enables technology-based growth **(Tassey 2000)**. Improved measurement methods for research and development, performance verification, process control, and efficiency in market transactions foster innovation and technology diffusion as well.

Investments in metrology and standards also generate spill-over benefits at the firm level, such as more effective stock control or the limitation of fraud **(Birch 2003)**. One very comprehensive book on the economics of standardization is **(Blind 2004).** The book provides a complete outline of the various types of standards and their possible economic impact. The links between standards, technological change, innovation and the regulatory system is also explored.

BENEFITS TO INTERNATIONAL TRADE

In today's globalized trade environment, legal metrology organizes the access to markets and provides a level playing field for businesses. Additionally, international compatibility, quality or measurement standards promote trade by lowering transaction costs, increasing consumer confidence or disseminating knowledge **(CIE 2006).** But the most prominent benefits legal metrology brings to international trade are expressed in terms of access to markets: the removal of non-tariff, Technical Barriers to Trade (**TBT**). It is the task of the OIML to facilitate the removal of TBT by harmonizing metrological requirements at the international level without hindering the development of free trade. Indeed, as **(Kochsiek and Odin 2001)** put it:

> *"Reliable and comparable measurements play an important role in many cases for the requirements to be met by the products and services (which may be different in the individual states), as do the various approval and test methods laid down by the responsible authorities. But the latter may themselves turn into barriers to trade, defeating the object of the exercise."*

International and regional organisations concerned with metrology and conformity assessment, recognizing the new challenges posed by the rapid globalization of trade, have begun cooperation. Most have also published strategy papers on the subject (e.g. the “Blevin report” (BIPM 1998) for the Metre Convention and the “Birkeland study” (Birkeland 1998) for the OIML). Metrology organisations have cooperation agreements with the main international trade organisations, such as the World Trade Organisation (WTO). The WTO “TBT agreement” provides advice to metrologists on harmonisation and requires national technical regulations to be transparent, justifiable and non-discriminatory. Other cooperation initiatives include meetings with the Organisation for Economic Co-operation and Development (OECD) and joint workshops on metrology with the United Nations Economic Commission for Europe (UN/ECE).

Harmonizing the technical regulations to facilitate world trade is also the role of the BIPM. A major advance in the removal of TBT was made in Paris during the 21th CGPM (the General Conference of the Metre Convention or *Conférence Générale des Poids et Mesures*), on October 14, 1999 when representatives from 38 national metrology institutes (NMIs) and two international organizations signed a Mutual Recognition Arrangement (MRA). The “CIPM MRA” – its full title being *Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes* – specifies that NMIs can become a part of an international network of metrological bodies producing reliable and comparable results either by self-declaration and disclosure of their means and methods, or by formal accreditation by competent authorities.

The international network of metrological organisations ensures precision in demonstrating conformity to written standards or specifications. Those are often the result of the political process of government, even if the border between public and private standards is often unclear as many standards are public by law but are based on the work of private standard-setting organisations (WTO 2005). Legal metrology thus forms a network connecting international organisations, political decision-making at the national level and virtually all economic agents. In that sense, legal metrology can be seen as a link between the political and economic fields.

This element is also important for it helps economic agents benefit from network effects. A network technology is a technology where users benefit not only from its inherent value but also from the size of the community of users. Two “laws” of economics illustrate this mechanism: Metcalfe’s Law (regarding telecommunication networks) and Reed’s Law (the utility of large networks, and specifically social networks, scales exponentially with the size of the network). The more widely accepted standards are established for, say, connectivity in electronics, telecommunication frequencies or content format such as Blu-Ray discs (JSA 2005), the more the community of users benefit from those technologies.

QUANTIFYING THE BENEFITS OF LEGAL METROLOGY

In order to design effective tools for assessing the economic benefits of legal metrology, we must know exactly where to look. At a basic level, metrology is usually divided into three main categories. Scientific metrology maintains and develops accurate standards; Industrial metrology cares for measuring instruments used in production and testing processes, as well as measurements for quality of life and academic research; finally, Legal metrology ensures adequate measurements where they influence the transparency and quality of economic transactions. Such situations include instruments subject to specific legal requirements or the need for measurement traceability. Indeed, one of the core functions of legal metrology is to provide the necessary infrastructure for the traceability of regulated measurements and measuring instruments.

Legal metrology provides methods and guidelines for maintaining the material conditions for trust and confidence in economic transactions through its international recommendations and its compliance and enforcement programmes. In metrological terms, a crucial part of this system is referred to as the “traceability chain”: an unbroken chain of comparisons, going back to one or more fundamental standards. Such a device requires good communication between multiple actors involved in metrological activities: standards-setting, accreditation, instrument testing, measurement etc. The traceability chain is established through mutual recognition agreements or arrangements (for example the CIPM MRA and the ILAC MRA, the arrangement between accreditation laboratories) as well as peer-review.

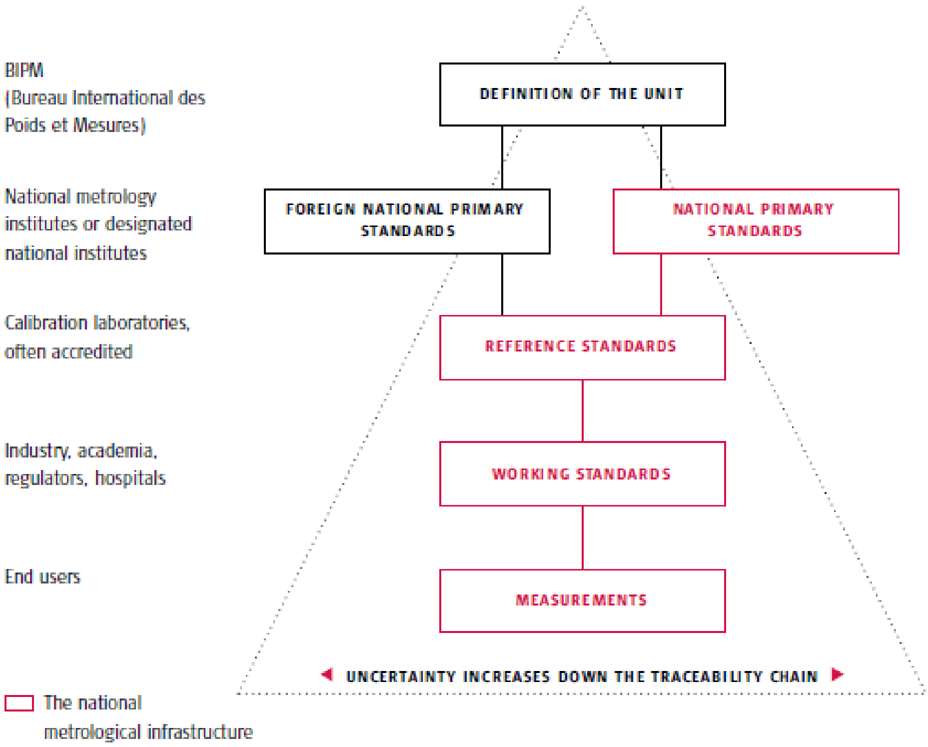
In order to facilitate conformity to standards and limit uncertainty in measurement results, legal metrology organisations use reference procedures. Such procedures are used to characterise reference materials or to define reference values. The former are used to measure a certain quality in a commodity, as a parameter of its price. Reference quantity values serve the purpose of establishing a maximum permissible measurement error. Both elements are translated into legal standards for producing and selling, and are thus embedded in virtually all value-creating processes. The volume and density of such legal metrology standards (or “stock” of standards) are sometimes used as a proxy to assess the level of investment of a given region, country, industry or firm in legal metrology and the benefits that it entails.

Maintaining a solid and metrological infrastructure, in collaboration with international authorities in metrology, and translating this operation in laws for trade, production or safety is a process that involves every part of public life. It is thus understandable that quantifying the benefits of legal metrology and providing tools readily available to decision-makers for the assessment of the benefits of metrology research or investment is not an easy matter. In the literature on the economics of measurement, different approaches to calculating the benefits of legal metrology have been used or suggested:

- Measuring the added value of government-financed metrology research programmes;
- Using the stock of standards as a proxy for standardization or the activity of metrological institutes;
- Using patents and publications in metrology as a proxy for metrology investment and activity;
- Conducting sectoral case studies to identify industry-specific drivers of growth;
- Using specific guidelines produced by standard-setting organisations to assess the benefits of legal metrology standards.

Overall, all studies have concluded that there is a clear economic benefit in investing in metrology programmes and national metrology institutes (Kaarls 2003) p.118.

Figure 1: The traceability chain



Source: *(Howarth and Redgrave 2008)*

THE ISO METHODOLOGY

Assessing and communicating the benefits of standardization is paramount for standard-setting organisations. The International Standards Organisation (ISO) has published a broad methodology to evaluate the impact of standards on value creation (ISO 2010). ISO set up a basic framework to represent the value chain in most business-oriented organisations, and allow for the identification of where and how standards affect the creation of value.

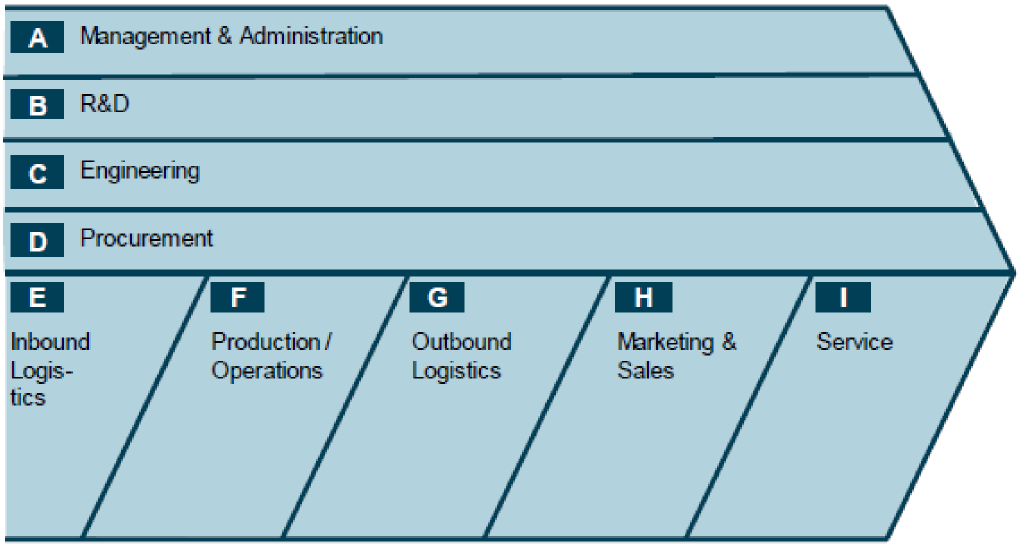


Figure 1: Model Value Chain in ISO 2010 p.3

The ISO methodology relies on a "Standard Impact Map", which "*lists the generic impacts from standards*" by business function in the value chain. Other tools are then used to place the organisation in its industry or sector and understand the specific impacts of standards that may occur there, as well as to produce a valuation of generic standards in their own context.

III) MEASURING THE IMPACT OF LEGAL METROLOGY ON GROWTH

LEGAL METROLOGY, STANDARDS AND INNOVATION

It is fair to say that achieving a direct and perfect measure of the intensity of legal metrology activity is not possible, for it is too closely intertwined with every economic process. In addition the practice of legal metrology is closely linked to scientific and industrial metrology. As Paul Temple **(Temple 2009)** puts it:

"As formal written documents, standards provide codified information regarding measures, reference materials, and processes which frequently support the other functions of standards, e.g. in the provision of legal metrology."

Indeed, defining norms and requirements regarding measuring instruments for trade and ensuring that those are followed relies on scientific and industrial metrology. In addition those norms will be highly dependent upon the current industrial standards. Using proxy to estimate the economic impact of legal metrology is however possible. For instance using the budget of the national institutes that are in charge of defining and enforcing those norms can be a relevant strategy to estimate legal metrology's impact. Evidently it does not account for how adequately this money is spent and its actual contribution to the effectiveness and reliability of legal metrology. Legal metrology involves the same actors as the process of standardization does, and its benefits to the economy and society are of the same nature as those of standardization. Standardization brings benefit to the economy by stimulating innovation and productivity. Legal metrology ensures that those benefits are realised through assessment of conformity to legal requirements derived from standards. Consequently, studying the methods for quantifying the impact of standardization on the economy is a good starting point to estimate the benefits of legal metrology. The stock of standards produced and the amount of publications by national metrology institutes are good proxies for their activity. Ultimately, such measures are used to analyse the benefits of standardization. The next section will present some of the works that have been done to estimate the economic impact of standardization since the same methods can be used to identify the economic benefits of legal metrology.

Developing and implementing standards as well as investing more in national metrology institutions must be justified by the benefits it entails. Some types of benefits, such as an improvement in quality of life, can be difficult to measure but may be the most central contributions of standards to society. It is delicate to obtain a value properly evaluating the benefits of good air quality or trust and confidence in a business environment, for example. Many studies focus on the benefits of legal metrology at an aggregate level. These studies usually concentrate on the relationship between macroeconomic variables such as the average aggregate labour and capital productivity and the stock of standards or government spending in metrology-related institutions.

The main idea behind this type of estimation is that the development of standards and the work of national metrology institutes drive innovation and productivity. Increases in innovation and productivity can be translated in terms of GDP points since they tend to boost production, exports and trade. The "BERL report" for example (Stokes, Dixon et al. 2011), states that the development of standards helped achieve an additional 564 million of New Zealand dollars in export volume, corresponding to an increase of 0.8 percent of the total volume of exports.

The link between legal metrology and innovation is made clear in many publications. The product of the work of legal metrology institutes, standards and publications regarding legal metrology requirements, can be decisive to innovation activities for various reasons. In the Schumpeterian view of progress, there are three key concepts when dealing with technological change: invention, innovation and diffusion. Standards play a role in all of these mechanisms. First of all, as described in the BERL study, a standard is a vessel for knowledge and technology diffusion. The information embodied in a standard can belong to industry process optimization, resource use monitoring or product safety best practices. Standards can ensure the diffusion of new technologies, new products or new ideas as explained in the "CIE study" (CIE 2006) where the authors consider standards as a language:

> *"The process of writing a standard — engaging committee members, preparing drafts, coming to consensus (in the approach that Standards Australia uses) is a process of distilling a variety of knowledge and practical experience into a document or set of documents that can be used and understood."*

In order to have a positive effect on economic development B. Verlag (Verlag 2000) states that:

> *"New products and improved methods of production must quickly assert themselves as broadly as possible".*

In addition to supplying a vessel to diffuse innovation, standards can enable innovation, as P. Swann puts it, by helping *"create a strong, open, and well-organized technological infrastructure that will serve as a foundation for innovation-led growth"* (Swann 2000). New technologies or new processes can be built on this foundation.

However, when considering legal metrology activity and innovation one must not forget that a positive correlation is not obvious. Indeed if we consider legal metrology, many authors have remarked upon the fact that standards can also hinder innovation. When observing the link between innovation or technological change and metrology, the timing of metrology work is paramount: if introduced too early, standards can prevent innovations to enter the market. In addition to this timing issue, the number of standards in a certain sector can also play against innovation (Stokes, Dixon et al. 2011).

In the 2005 DTI study (DTI 2005), P. Swann focused on the following question: "Do standards enable innovation?" Using data from the Community Innovation Survey (CIS), he was able to question the informative role of standards and whether they exert a constraint on innovation. The PERINORM dataset contains information on the stock of standards, particularly its size and its median age. Combining those two datasets, P. Swann used two ordered logit models: one estimating the informative role of standards, and one estimating the constraints standards put on innovation. If we consider the result about the constraint on innovation, it appears that the relationship is non-monotonous: when the number of standards increases, producers find them less constraining but after a certain point they become more restrictive. It appears to be the same with the age of the standards stock relevant to a specific industry.

Legal metrology and standards can be drivers of technological growth and stimulate GDP, but must be meted out carefully so as not to hinder innovative activities and growth. The studies linking aggregated variables, such as total factor productivity and a measure of legal metrology activity, do not presume of the sign of the relation between those variables, but merely observe what emerges from the data. The aim of the following section is to review some papers studying the impact of standards at a national level and how the activities of national and international standards-setting authorities have an impact on innovation, productivity, growth and social welfare.

In the next section, we will review different approaches. Some estimate the link at the macroeconomic level between the stock of standards, NMI publications and the aggregate average labour productivity. These kinds of studies allow for a monetary evaluation of the economic value of standards and of the work of NMIs. We will first consider the studies that associate the stock of standards to productivity or directly to GDP. We conclude this section by considering studies of the impact of public spending in legal metrology and metrology in general.

EMPIRICAL ESTIMATIONS USING THE STOCK OF STANDARDS

From one study to another, the stock of published standards may be used as a proxy for the activity of National Metrology Institutes or for the degree of standardization. The advantage of this measure is that it is available for an extended period of time. Hence its relation to GDP, growth or total factor productivity can be estimated with time series analysis. As we explained before, a literature review of this type of study is pertinent when studying legal metrology since the economic benefits are similar. In addition, since there is a large number of studies on this subject, there seem to be a consensus that time series analysis is relevant to estimate the benefits of standardization and the work of metrology institutes.

The study developed by **(Jungmittag, Blind et al. 1999)** introduces the stock of standards in the production function and investigates its effect on the output. A co-integration analysis is used for German data from 1961 to 1996. Their results indicate that the stock of standards does have an effect on aggregate activity and on economic growth. The DIN study, also using German data, finds a positive influence of the stock on standard on innovation and on the economy as a whole **(Verlag 2000)**.

The DTI study of 2005 reproduces the methodology used by Jungmittag et al. on U.K data, from 1948 to 2002 (**DTI 2005**). This paper associates, with a production function, a set of inputs to a measure of standardization and to the output. The inputs used are the ones traditionally considered: capital and labour. The authors use a Cobb Douglas production function, classically used in growth studies. Technological change acts as a multiplicative factor of the traditional inputs:

$$Y = A(t)K^{\alpha}L^{\beta}$$

Where A(t) is technological change and K and L respectively capital and labour inputs. Technological change is a vector of Z(t), a series of factors containing the stock of standards:

$$A(t) = A\big(Z(t)\big)$$

With A defined as a multiplicative factor. Technological change is also a vector of domestic innovative activities and the import of technology from abroad. The stock of standards is a good measure of the diffusion of innovation.

$$Z(t) = \exp(\lambda t)\, Pat(t)^{\gamma} LEX(t)^{\delta} STD(t)^{\epsilon}$$

Where *Pat(t)* is the stock of domestic patents at time t, *Lex(t)* is the imports of license and *STD(t)* is the effective stock of standards. If we apply a logarithmic transformation to the variables (lower case letters), the production function becomes:

$$y(t) = a + \alpha k(t) + \beta l(t) + \gamma pat(t) + \delta lex(t) + \epsilon std(t) + \lambda t + u(t)$$

In that study, the estimations with the complete model were considered inadequate due to the large number of parameters to estimate. One issue was that standards and patents were highly co-linear. Consequently, the authors worked on a reduced form, imposing constant return to scale and linking labour productivity to the labour and capital inputs and only the stock of standards to model technological change. Here the imposition of constant return to scale is $\beta = 1 - \alpha$. So the model estimated is now:

$$y(t) - l(t) = a + \alpha\big(k(t) - l(t)\big) + \epsilon std(t) + \alpha t + u(t)$$

Following this estimation the authors produced a co-integration analysis to see if the relations they estimated were spurious. Their results suggest that the stock of standards did influence labour productivity, and not the opposite. They found that a one percent increase in the stock of standards is associated with a 0.05 % increase in productivity.

This type of study was reproduced in many different countries. Haimowitz and Warren used a similar analysis on Canadian data and also obtained a positive relationship between the stock of standards and labour productivity **(Haimowitz and Warren 2007)**. Their results are similar to those of the DTI study. A 2009 report for AFNOR **(Miotti 2009)** used this model on French data, the difference being that total factor productivity (**TFP**) was considered instead of labour productivity only. The stock of patents is also used in this regression and they find a larger effect of the stock of standards. In Australia, the Centre for International Economics (**CIE**) also obtained results suggesting a positive effect of the standards on productivity **(CIE 2006)**.

However, the authors generally mention that these results must be taken with caution since the tests applied to the data are imperfect and do not prevent from estimating spurious relationships. Spurious relationships can occur for different reasons: missing variables affecting both the stock of standards and productivity but unrelated to legal metrology, reverse causality problems or simultaneity issues. This study also presents a variation of the model used previously where the stocks of standards and R&D constitute the stock of knowledge. They use different computation of this stock of knowledge, using these two variables. In their second approach, it is the effect of the stock of knowledge on TFP that is estimated. It is, as they explain, not equivalent to introducing both the stock of standards and R&D in the regression.

The study is reproduced for New Zealand **(Stokes, Dixon et al. 2011)** and also estimates, with a Cobb Douglas production function, the effect of the stock of standards on total factor productivity from 1950 to 2011. The estimated impact of an increase of one percent in the stock of standards is associated with an increase of 0.10 % in productivity. Finally, in 2013, Spencer and Temple produced the same type of analysis but this time only considering the British Standards Institution (**BSI**) catalogue, to examine the role of one particular organization on aggregate productivity. They began by estimating an unrestricted VAR model (Vector AutoRegressive) and then performed co-integration tests. They also found that standards play a significant role in long term productivity growth. One of their important results is that standards would not be affected by short term productivity growth, suggesting that for these data there are no issues of reverse causality.

These reports surveying the relation between the stock of standards and productivity growth present some interesting results. The net advantage of using this type of data and methodology is that it provides a sufficient number of points to estimate a satisfactory econometric model. However, if the aim is to study the benefits of legal metrology, the stock of standards is an imperfect proxy. It can give some indication of the impact of legal metrology activities but quantification will necessarily be imperfect since the proxy doesn't entirely covers the benefits of trade regulation based on those standards. Surveys of key stakeholders can provide comprehensive results on how legal metrology can benefit the economy at large, but estimating an economic impact in term of GDP may be more difficult. It is however possible to analyse the benefits of public spending in metrology institutes or by focusing on certain metrology programs. The following section presents a selection of such studies.

SPENDING IN METROLOGY AND AGGREGATE PRODUCTIVITY

In 1999, the National Measurement System Policy Unit of the Department of Trade and Industry commissioned a study on the economic benefits of the National Measurement System (NMS) in the U.K. **(DTI 1999)**. We must underline that some of the programs covered by the National Measurement System are qualified as falling under legal metrology (DTI 1999). The researchers used survey data but also presented an estimation in GDP terms of the benefits associated with metrology as a whole. It found that the UK NMS impacts positively the economy through four main channels: by maintaining the measurement infrastructure, by supporting innovation, by enabling fair and safe competition and by representing the UK in international coordination of the measurement systems. The approach used here consists in determining first which proportion of GDP growth can be attributed to TFP growth. Then the proportion of TFP growth due to knowledge growth is calculated. Finally the proportion of knowledge growth due to metrology inputs is allocated. These successive allocations authorises estimates of the contribution of metrology inputs to GDP growth.

In order to realize such allocations, the authors reviewed extensively the relevant literature. They estimate that 20 % to 25 % of GDP growth can be allocated to TFP growth. 60 % of available knowledge comes from domestic sources and the authors assessed that 10 % of this knowledge can be attributed to metrology inputs. The computed estimate of the impact of metrology on GDP in the UK is thus, from 1990 to 1998, £5 billion per year (in 1995 prices) which amounts to 0.8 % of GDP. Another study on the U.K (NMO 2009) develops a method to estimate the impact on the U.K economy of increasing the budget of the National Measurement System by 10 %. It is assumed that the purchase of instruments, of technical standards and the volume of expert services offered vary proportionately with this budget. Using results concerning the elasticity of productivity with the level of innovation and the elasticity of innovation to measurement knowledge, an increase of 10 % in the budget of the National Measurement System would lead to economic gain between 300 and 400 million of pounds. Bowns et al. (2003) analyse the Mapping Measurement Impact model (MMI) of the U.K which consists in a method to evaluate the benefits of publicly financed programs. They describe and analyse the improvement made to this program which is used by the UK DTI to evaluate the project funded as part the British National Measurement System (NMS).

(Poposki, Majcen et al. 2009) develop an original approach by using data on the sales of measurement instruments. This paper evaluates whether the countries that have a better quality of life, using the Human Development Index (HDI) as a proxy, spend also more on measurements. They find a positive correlation between those two variables. Following this they put forward descriptive statistics concerning public spending in metrology for a few European countries in the form of their NMIs budgets. They analyse these data against the national HDI.

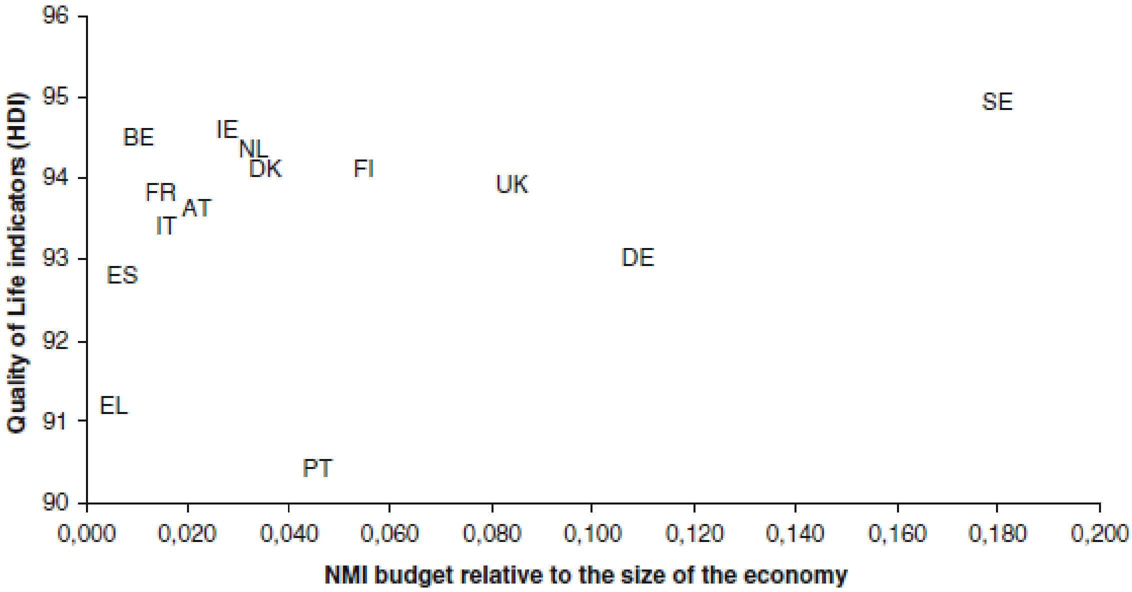


Figure 2 Relative NMIs spending compared with quality of life indicators. Source: (Poposki, Majcen et al. 2009).

The authors proceed to use the internationally recognized calibration and measurement capabilities (CMC), defined by the Mutual Recognition Arrangement, of each National Metrology Institute estimating that they constitute a better proxy for public spending in metrology. They stipulate that it is still an imperfect measure of public spending since the costs of maintaining a number of CMC may vary from one CMC to another. More investment in R&D in metrology is associated with higher HDI. These authors explain that the evaluation of the benefits one can expect from spending in metrology will probably increase in the following year since the social demand for government accountability is increasing.

This demand for more evaluation of the benefits associated with spending is illustrated by the European Metrology Research Programme (EMRP) set up by EURAMET, the association of European NMIs. Indeed, there is a greater demand for ex-ante and ex-post evaluation of the benefits associated with the allocation of money between different projects in order to prioritize and ultimately guide the allocation of public funds.

IV) GUIDELINES FOR AN ECONOMETRIC ANALYSIS AT THE MACRO LEVEL:

There are a number of macroeconomic studies putting forward a model for estimating the impact of standards on productivity and growth. Here, we will present a simple version of the macroeconomic model and its possible extensions depending on the data available.

To perform this type of estimation we either need data from a large number of countries or time series for at least one country. The model is usually designed for a single country and estimated for a period between ten and sixty years. The objective here is to explain a macroeconomic aggregate (productivity, growth, added value) with explanatory variables that include an acceptable proxy for legal metrology in order to quantify the impact of this factor. To properly identify this impact, control variables have to be included in the model: namely the national stock of capital and the amount of labour put in the production. The basic version of the model is given by:

$$y(t) = \gamma + \alpha k(t) + \beta l(t) + \delta LM(t) + \epsilon$$

Where k is the stock of capital at time t, l the stock of labour at time t and $LM(t)$a proxy for legal metrology at the same time.

The first methodological choice to consider is the explained variable. It depends on what we seek to know: do we want to quantify an impact on total factor productivity, on labour or capital productivity, on sectorial growth, on national growth, on global growth, on social welfare (using the HDI index, for example)? To choose this variable, the scale at which the analysis is realized must be decided: a sector, a country, a group of countries etc. In most studies, productivity is examined at a national level (TFP or labour productivity).

The second methodological choice is the proxy for legal metrology. The most widely used is some variation of the stock of standards, although it is imperfect in a number of ways (see beginning of Section III). However this variable presents different advantages: it is easy to compute because different organizations keep track of this stock. Besides, it is often available for long periods of time. An alternative is to use the number of publications of metrological institutes in addition to this stock. Another interesting variable concerning legal metrology would be the national budget of metrological institutes or the public spending on that matter. We can also use the certification cost for industries **(Usuda and Henson 2012)** along with the precedent proxies. However this operation should be done with caution to avoid any possible omitted variable bias. Such bias occurs when factors influence both the explained variable and at least one explanatory variable. So, when adding public spending in metrology, one must be sure that it is not correlated with an omitted variable that would affect the explained variable (i.e. productivity or output).

The missing variable bias is an inherent problem to this kind of estimation and it is very likely that the model with only the stock of standards also suffers from it. Indeed it is very likely that the stock of standard and the explained variable are both strongly correlated to innovation and technological change. Proxies for innovation should thus be added in the model and many authors do so (cf. part III). The estimated equation becomes:

$$y(t) = \gamma + \alpha k(t) + \beta l(t) + \delta LM(t) + \phi Tech(t) + \epsilon$$

Where $Tech(t)$ is a proxy for technological progress at time t. Such proxies can include the stock of domestic or imported patents, spending in R&D, performances in research and education etc.

The model can be extended for more than one country, as done in **(Temple, Blind et al. 2005).** Estimating the model for multiple countries allows for the introduction of country-fixed effects coefficients. Including those reduces the omitted variable bias since they control for unobserved effects constant over time. For n countries, the model is now:

$$y_i(t) = \mu_i + \alpha k_i(t) + \beta l_i(t) + \delta LM_i(t) + \phi Tech_i(t) + \epsilon_i$$

Where i indicates the country.

Once estimated, the model could be a useful addition to the toolbox already available to researchers and decision makers who seek to assess the impact of legal metrology on the economy and society. The estimated coefficient δ represents the effect, all things being equal, of legal metrology on the national product.

V) LESSONS LEARNED FROM SECTORIAL CASE STUDIES

In order to better apprehend the benefits of legal metrology, the next section analyses the microeconomic foundations of the models explained before. More specifically, we will describe the benefits of metrology and standardisation for microeconomic actors by focusing on sectorial studies and theoretical microeconomic analyses of standardisation impact. The scope is twofold: after summarising the main benefits from the producers' point of view, we will point out the gains for consumers mentioned in the literature. More often, the sectorial studies on that topic do not give any numerical estimation of the benefits of legal metrology or standardisation at large. Indeed, this estimation is not easy to produce because of the lack of a counter-factual. Even though, the authors provide a fairly exhaustive list of these advantages and explain the underlying mechanisms behind the link between metrology, and its translation into legal requirements, and welfare.

BENEFITS FOR PRODUCERS

TRANSACTION COSTS REDUCTION

Transaction costs refer to the costs incurred when making an economic transaction. They also refer to the price agents need to pay in order to enter a market. These costs can incur at each step of the transaction: before the transaction, *search and information costs* refer to the costs of looking for a potential buyer for second-hand goods, for instance. During the transaction, *bargaining costs* relate to the costs of establishing a contract and making the transaction happen (for example, transportation of the goods). After the transaction, *policing and enforcement costs* refer to all the costs of verifying that every Party comply with the contract.

Businesses have to minimize such costs when working together. They must find a contract in their best interest and make sure everything takes place according to the terms defined beforehand. Even if the contract builds a legal obligation, one cannot be certain of the other Parties' behaviour. This uncertainty is a market failure in the extent that uncertainty often leads to an equilibrium different from the economic optimum. For example we can imagine two economic agents willing to make a deal but deciding not to in order to prevent themselves from a risk of non-compliance.

The Case study led by BERL Economics **(Stokes, Dixon et al. 2011)** is a good example of how standards can help mitigate this risk and the associated costs. The study concentrates on the building construction sector in New Zealand. Interviews with the main stakeholders of the industry were undertaken to assess the role of standard, in reducing cost and uncertainty. There is a wide range of standards in this industry ranging from process specifications to performance requirements. These standards can be either mandatory or voluntary. The revision of one of these standards (NZS 3910:2003) included provisions for "*the clear identification of risk allocation, assurance of fair treatment for the contractor and the principal* *and clearer insurance requirements*". Indeed, stakeholders in the building sector face a high uncertainty; the Principal could suffer from the delay in the execution of the project. At the same time, the contractor could suffer from an environmental or climate risk and could not be held responsible for the delay. The standards make clear who has to carry the risk:

> *"The key things the Standards does is that it says, once the project starts most things that happen are at the contractor's risk. They are on-site and know the business of construction, so a Standard like that passes the care of the works to the contractor but it can't pass all that risk as there are certain things that the principal must carry – the accepted risks – things like the design works, decisions that have been made about the materials that will be used. The principal carries this risk as they made that decision. These risks also include things that the contractor can't take out insurance to protect themselves from. Those care of the works provisions are a large part of the Standard."*

(Interview quote from Andrew Bricknell, Director of Project Management Asia-Pacific, MWH)

Additionally, the standards not only focus on the aspect of responsibility but are also "solution-driven" in the extent that they disseminate expectations on payment delivery and timing and suggest solutions in the case of non-compliance with the contract.

Standards also lead to a reduction of searching costs, which can occur at all stages of the transaction: they represent the cost of finding a contractor and verifying he is acting accordingly to the contract. **(Den Butter and Groot 2007)** describe mechanisms by which standards reduce transaction costs. Without any specification of product, the search for a good seller would take a lot of time. Besides, the contract would have to describe every characteristics of the traded good or service without being able to refer to any known category. Standards thus allow focusing only on the price and delivery conditions during the information search but also during the contract redaction. This leads to an important decrease in transaction costs. Butter et. al. illustrate this standard benefit with an example in the automobile industry:

> *"After standards were introduced, it was no longer necessary to search for a supplier that could produce the parts that were needed in a specific situation. Search costs decreased and using external suppliers became more profitable. Apart from search costs, contracting costs were also reduced. Contracts between the producer and its suppliers did no longer have to be specified extensively. Clearly this also reduced enforcement costs."*

PRODUCTIVITY INCREASE

In a 2009 study, Swann **(Swann 2009)** explains how a better knowledge of raw products induced by legal metrology requirements and standardisation lead to cost reduction and increased productivity. A case study of Plasterboard production in the UK shows how standards can enhance the production process. Plasterboard is produced from paper and gypsum. A good measurement of the raw materials and of the intermediate products allows adjusting the production process. This is all the more important than a lot of quality variation in the final product can be attributed to quality variation in the raw product (and the variation in quality intensifies for natural products). Standards and automatic measurement lead to an increase in the accuracy of quality test.

Before the implementation of standards, a sample of the raw material was taken and tested for characteristics. Now each piece entering the production process is automatically tested so that the quality of the product is known at every step of the process. This way, the production process can be adjusted in order to prevent from a variation in the quality of the final product. This improvement in measurement-related procedures and processes led to a better quality of the final product but also to a more accurate description. This example thus shows how investing in measurement capacities reduces the market failure induced by information asymmetries.

Another source of uncertainty encountered by economic agents is environmental by nature. Environmental uncertainty refers to all the unknowns about environmental parameters that could influence profit. For instance, a wheat producer faces uncertainty concerning the future demand for his product in the next few months, but also regarding the climatic conditions on which his final supply depends. This kind of uncertainty leads to specific costs (insurance costs for example), a decrease in productivity and a less efficient stock management. Environmental risk often refers to this latest sense. Firms facing high environmental risks may invest in an effective way to mitigate it, and legal metrology is key to that operation.

In a study for the Canadian standards-setting organisation **(Haimowitz and Warren 2007)**, the authors complete their econometric study with a case study of SaskPower, a full-service Canadian utility. SaskPower registered to ISO 14001[3], a set of environmental standards. According to SaskPower, standards adoption led to risk management benefits:

> *"Overall, SaskPower believes that it is operating more efficiently as a result of implementing ISO 14001. These efficiencies have allowed SaskPower to do more things with the same resources and to do other things more diligently."*

The standards aim to reduce the environmental impact of the firm; they did not directly affect the measurement system as in the Plasterboard case. The mechanism to explain how the firm benefits from these standards is different: because the ISO registration implied limiting some production spill overs that could affect external parameters which determine total profits, the standards adoption resulted in higher productivity and a better adaptation to the company's

[3] « The ISO 14000 family addresses various aspects of environmental management. It provides practical tools for companies and organizations looking to identify and control their environmental impact and constantly improve their environmental performance. ISO 14001:2004 and ISO 14004:2004 focus on environmental management systems. The other standards in the family focus on specific environmental aspects such as life cycle analysis, communication and auditing. » http://www.iso.org/iso/iso14000

environment. The impact of standards on these productivity gains are very difficult to quantify because the factors are numerous and highly correlated. One should be careful when assessing the isolated impact of standard adoption. This quantitative pitfall can be avoided by qualitative examination (*e.g.* interviewing people involved in the standard adoption process):

> *"In 2005, the most recent year for which data are available, SaskPower had 15 reportable spills, which was slightly under the 5-year average. One might ask two questions: Was the result significantly positive[…] The decrease is probably indicative of a positive result because over the previous 5 years, SaskPower had added facilities and increased the number of employees all items which could be expected to increase the potential for spills. […] SaskPower is convinced that ISO 14001 implementation has definitely helped it to manage and avoid environmental risks. SaskPower believes that it has benefited significantly by implementing ISO 14001. Management has increased confidence that through the rigor of ISO 14001 and the discipline imposed around the identification of negative consequences, environmental risks are being identified and better managed. Risks have always been managed at SaskPower […] but since ISO 14001 was implemented procedures have been improved, quality training is in place, and documentation and record keeping is better."*

By registering to the ISO standards set, SaskPower also improved its audit system. ISO 14001 includes requirements to define and communicate targets. The audit process has been designed such as each negative result is followed by a procedure aiming at fixing the malfunctions. This way, the company in the study was able to constantly improve its production processes and its productivity.

ACCESS TO NEW MARKETS

An important benefit of standards mentioned in the literature is the opportunity to access new markets. This can be done either by productivity gains allowing producers to take part in a very competitive market or through the compliance to legal requirements necessary to enter the market. In the same survey **(Haimowitz and Warren 2007)**, the authors study the case of INFASCO, a producer of standard steel fasteners playing a front role on the global market. The conclusion of the authors is clear: the registration to ISO 9001 and ISO/IEC 17025 accreditation enabled the firm to stay in business despite the highly competitive environment implied by the presence of low-cost fasteners from emerging market countries.

The example of the Building sector in New Zealand reviewed by **(Stokes, Dixon et al. 2011)** shows how investing in standards can help firms gain an interesting position in a particular market. In this example, the national programme "Warm up New Zealand" produced benefits for consumers using the insulation system:

> "*Anyone who has a home built before 2000 is eligible for 33 percent off the cost of installing ceiling and under floor insulation up to a maximum of $1,300. Community Service cardholders can get 60 percent off the cost of installing insulation*."

To be eligible, consumers have to choose a specific insulation system complying with a set of requirements defined by the Energy Efficiency and Conservation Authority. Building companies offering equipment and installations fitting with these requirements thus have a profitable position in the market since the demand for their goods and services increases. In this particular case, the first company offering this insulation system has a quasi-monopolistic position. To be able to sell this system at the time when the programme is implemented is possible only if the companies invest in legal standards and even take part in the drafting process at an early stage as consulted stakeholders.

Indeed, participation in standard design enables firms to achieve a good market position. In **(Shintaku, Ogawa et al. 2006)**, the authors focus on the electronics sector. The *International Electrotechnical Commission*[4] gathers experts to discuss and develop new standards. To explain how standard participation increase market share, the case of Tyco Electronics/AMP is studied. This company produces connectors and interconnection systems. When deciding to produce a new type of connector, firm representatives also joined the committees designing the relevant standards. The idea was to influence the process to their advantage by convincing other stakeholders of the superiority of their technology. Eventually, the new connector was used to set the standard, giving Tyco Electronics/AMP a significant competitive advantage on the markets they were operating in. Because this connector used a more elaborated technology, the profit margin of the company also increased due to higher prices. The authors quantified the gain induced by this new market share with the following results:

> *"[…] in the period 1995-2004, the combination of better market share and better profit margins has provided Tyco/AMP with additional profits estimated to be in-between US$ 50 000 000 and US$ 100 000 000. Without the investment in standardization this probably would not have been feasible".*

Another case study by the same authors shows that, even if the company is not participating in the standard-setting process, it can benefit from staying informed of the latest modification in the legal metrology requirements or certification process. Intergraph produced software and hardware goods. They conceived a computer for graphical applications and the keyboard did not meet the international standard IEC 60073. Before the beginning of the keyboard modification (which would have induced a cost of €19000 for only 1000 keyboards), a member of the committee organization heard that the standards stopping them from commercializing the product were being changed in a way allowing them to sell the computers as they were. Being informed of this new element too late would have incurred huge costs for the firm. In sectors such as Information Technology, standards evolve very quickly and have a large impact on the company profits because network and spill overs effects are omnipresent. It is then essential for firms to invest in standardisation, either by taking a decisional part in it or by staying informed of the latest developments.

[4] http://www.iec.ch/

We have seen how investing in and taking part legal metrology work can enable firms to access new markets or keep the upper hand when legal requirements change. We will now describe how standardisation can enable firms to create new markets in which they will have, at least in the early stages of its development, a monopolistic position. Indeed, as **(Swann 2000)** shows, standards play an essential role in product diversity. Above, we have highlighted the role of standards in fostering innovation. Swann builds a model to explain the impact of standard on process innovation. The author uses a characteristic analysis in which products are differentiated by the features they offer. Innovation leads to the development and commercialization of new characteristics and then allows for an increase in diversity. Every product can be located in a multidimensional space according to its characteristics. It is important that consumers understand the location of products within this virtual space. Yet this is only possible if sellers can provide accurate measurement about the product characteristic. The model shows that "*anything that expands the pool of feasible measurements can be expected to expand the pool of feasible product characteristics*". A main hypothesis of the model is that product innovation demonstrates "combinatorial characters" in the sense that a new product is a new combination of feasible measurable characteristics.

INFORMATION, QUALITY AND PRICE PREMIUM

We have mentioned before the role of asymmetric information in market failures. We will now describe the nature of this market failure and explain how measurement standards can help reduce it. In his famous article **(Akerlof 1970)**, Akerlof illustrates adverse selection with the example of second-hand cars. In this market, suppliers are car owners who try to sell their cars. Buyers are looking for a car but they are facing a risk induced by the lack of information about the quality of the car offered. The buyers face the risk of buying a defective car. Taking this risk into account, they lower their reservation price (*i.e.* the maximum price they are willing to pay for their second-hand car). Sellers of high quality cars are not interested in selling anymore with too low a price and are driven out of the market. Only sellers of low quality cars remain: this phenomenon is referred to as adverse selection.

Asymmetric information leads to market failure in the extent that some buyers were able to buy a high quality car for a higher price but the transaction does not occur because of this lack of information on the buyers' part. This means that the satisfaction of buyers and sellers would have been higher if the information was perfect. Asymmetric information is a widely studied research topic in economics and measurement standards appear to be an effective answer to this market failure. This is the proposition put forward by **(Swann 2009)**. According to the author, measurement standards do not only achieve market failure reduction but also allow firms to receive a price premium when they produce better quality goods. This mechanism leads to a higher average quality of the products offered. As we explained before, these kinds of standards allow producers to commercialize new products or better quality products. This investment in research and this improvement in quality are costly for the producer, who is incentivised to do so only if he expects his new product to meet a substantial demand.

Consumers who are offered innovative goods know they are taking a risk by buying: it may not be compatible with other, related goods (in the case of telecommunications, furniture or appliances, for instance); understanding all his functionalities may induce an information cost or it may simply not match the consumer's taste since the good is new on the market and has few recommendations from peers. It is then essential for producers to reduce the risk faced by consumers buying their commodities. An efficient way to mitigate this is to provide the consumers with more information about the product. Once the information about the innovative product is disseminated, consumers may agree to pay a higher price for a higher quality good; the producer receive a premium existing only as long as information is easily available thanks to standard measurements.

So far we have examined the benefits of norms and measurement standards from the producer's point of view. We will now complete this analysis with a review of the consequences for consumers.

BENEFITS FOR CONSUMERS

INFORMATION, QUALITY ASSURANCE, NEW PRODUCTS

As we have seen before, legal metrology increases the amount of information available about commercialized products. In turn, more accurate information facilitates innovation. Producers can enter new markets or even create one where they may have a monopolistic position for a time. This increase in the variety of available goods also improves consumers' welfare. They are more likely to find a product matching their taste and expectations, which augments their utility. Here, we use the term "utility" in the sense given to it by the consumer choice theory. Here is the simplest way to represent the utility associated with the purchase of a good i:

$$U_i = f(x_i, p_i)$$

With x_i the quality of the good i or any of its characteristic and the $p_i$the price of good i. The function f is increasing in x_i and decreasing in p_i. It is also often assumed that utility is increasing in the quality. Innovation would result in the production of a product with higher quality or more features. Consumers will benefits from an increase in goods quality since good quality is one of the main parameters determining their utility. The Dixit-Stiglitz model **(Dixit and Stiglitz 1977)** of "love of variety" shows that consumer utility increases with enough diversity of choice. The main hypothesis of this model is that products are horizontally differentiated, meaning that they differ in their characteristics – which all consumers are informed of.

In short, the hypothesis of perfect information about the products available on the market is essential to microeconomic models. According to these models, consumer utility and welfare increase with the quality and diversity of products. As we have seen earlier, the implementation of measurement standards and legal metrology requirements enable firms to produce higher-quality goods and to commercialise new products. But for legal metrology to increase total welfare, these standards and information about measurement rules and instruments have to be available to consumers. In (Swann 2009), the author stresses this point. He cites the work of (Bacharach 1990) who explains that even if economic studies explain product characteristic as defined by producers and sellers, it is useful to adopt a "customer-centred" view. According to P. Swann:

> *"this customer-centred view makes it clear why measurement methods should be open to sellers and buyers alike".*

Investing time and money in in legal metrology and measurement may then benefit the entire sector and the whole economy as long as the information about measured characteristic is known to all economic agents. This is why private and public investment in legal metrology enterprises are equally important to ensure economic growth and welfare.

SPILL OVER EFFECTS AND NETWORK EXTERNALITIES

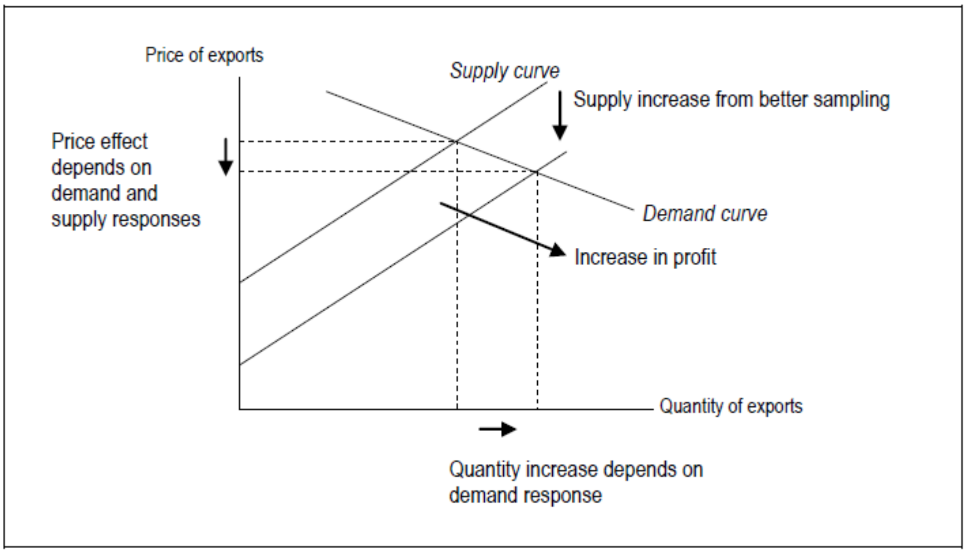
There are other non-direct benefits of legal metrology and standards to consumers. In sectors characterized by high network or spill over effects, metrological requirements can have an even more important effect on total welfare. The study of the Building Sector in New Zealand (Stokes, Dixon et al. 2011) shows that the increase in the quality of installations and insulation system also benefits households living in residential buildings. Furthermore, as the people installing this insulation scheme increase, the quality of the service offered by the building companies increase too:

> "*Between July 2009 and March 2011, 91,506 households have taken advantage of the home insulation and heating scheme. At least 10 percent of these households have been audited. There has been a huge increase in the quality of the installation of the insulation due to training by the Insulation Association of New Zealand related to NZS 4246:2006."*Quote from Tim Mahar, Senior Technical Advisor, Energy Efficiency and Conservation Authority

IMPACT OF MEASUREMENT METHODOLOGY

One important aspect of measurement that can benefit both consumers and producers is the methodology it uses. Indeed, as we have seen in the case study of the plasterboard sector, comprehensive and integrated measurements on the raw materials help to improve the production process and thus increase the final product quality. This increase in quality benefits producers and consumers alike if the product price is not too high. The possibility of a price too high for the supply to meet its demand is reduced by the increase in efficiency (as economic theory presents prices as highly correlated with productivity) made possible by standardisation. For some sectors, it is not possible to measure the characteristics of every single input: this is why the sample methodology is an important component of the firm's measurement strategy.

In **(CIE 2006)** the authors study sampling methods in the mining sector. When a transaction for selling minerals occurs, estimations about the mineral content have to be made in order to determine the price and quantity to be sold. It would be too costly to measure the content of each mineral, so only a sample of mineral is selected to be tested. The way this sample is chosen will determine the accuracy of the estimation. Producers have to choose the right statistical strategy since more accurate sampling would allow the seller to negotiate a higher price than otherwise. For the buyer, this would reduce the information asymmetry he faces in these kinds of transactions. The authors focus next on the gains in terms of profits for the producer when the supply increases. Their model depends on an estimation of supply and demand responsiveness (represented by the slope of the curve in figure 1). They estimate an average benefit of $58 million per year for the concerned industries.



Source: (CIE 2006)

VI) MODELLING THE MICROECONOMIC IMPACT OF MEASUREMENT

We will now build a model for quantifying the impact of measurement on the producers' profits. Because we want to focus on the benefits conformity to legal metrology requirements brings to the profit of producers, we won't include the costs induced by standard adoption or measurement investment at every step of the modelling. Instead we included a parameter for the cost of the whole operation of following legal metrology requirements. This model aims to explain profit by the factors most commonly used, as underlined in the literature review. Our methodology is inspired by producer microeconomic theory, which defines the maximisation program for producers as follows:

$$\begin{cases} Max_x & \Pi = p.y - C(x) \\ subject\ to & y = F(x) \end{cases}$$

With Π the profit; p the price of a good noted y; $F(.)$ the production function and $C(.)$ the cost function. This very simple representation helps to understand producer strategies. On the one hand, he wants to produce more because his profit is an increasing function of the quantity sold. On the other hand the cost is an increasing function of the quantity produced (second part of the equation). Under some hypothesis on the functional form of F(.) and C(.), this profit function presents a maximum defining the optimal amount of input to use which then defines the optimal produced quantity.

If we include the constraint into the objective function, we obtain this program:

$$Max_x \qquad \Pi = p.F(x) - C(x)$$

The mechanisms explaining the link between standard adoption, measurement improvement and profit increase have been listed before. We will include them in the production and cost functions step by step in order to get a comprehensive model embodying the economic effects of legal metrology and standardisation on producers' profits. Here, the cost function includes the costs induced by the production of the goods as well as all the other costs producers face during the sale proceeding. This approach is slightly different from the standard microeconomic framework where, in a perfect competition environment, there are no transaction costs and the price is the only adjustment mechanism between supply and demand.

This simple model will allow us to make a first step in trying to quantify the impact of legal metrology on profit. As we have explained before, the absence of a counterfactual prevents us from computing the benefits of legal metrology in monetary units. Yet, we can still translate how legal metrology work affects profit into a microeconomic model.

TRANSACTION COSTS

One of the essential benefits provided by standards and measurement is the decrease in costs incurred by firms. As we have explained, standards can reduce transaction costs by various means. For instance the input x needed to produce the good y can be provided by an external supplier. In this case, the producer might need to establish a contract to schedule a weekly delivery, for instance. The producer then faces what we have called *policing and enforcement costs* to make sure the supplier behaves according to the contract. There are different ways to include these costs in the profit function. We assume that *policing and enforcement costs* can be proportionate to the quantity of inputs to be acquired by the producer. For these situations, we can elaborate a factor t_1 strictly positive and multiply it by the quantity of goods x. This parameter encapsulates all the variable costs, increasing with the quantity produced. Thus, the cost function becomes:

$$C(x) = t_1.x$$

Search and information costs as well as *bargaining costs* are conditional to the transaction and they don't necessarily increase with the quantity traded. They can be included in the cost function as a fixed cost, which means adding an additive factor to the cost function:

$$C(x) = t_1.x + t_2$$

According to the standard industrial economy, in the short run, the only variable producers can choose is the quantity x used to produce the output y. However, in the long run, producers can choose the technology they use (*ie.* modifying the production function). For example, investing in a new machine improves the technology by modifying the labour/capital ratio of their production. As we have seen before, the adoption of a new standard can reduce transaction costs. Consequently t_1 or t_2 could decrease to t_1' and t_2' with $t_1' < t_1$ and $t_2' < t_2$. Since profit is decreasing with cost, this would increase profit.

$$\Pi' = p.F(x) - t_1'.x - t_2' > \Pi = p.F(x) - t_1.x - t_2$$

Besides, investment and participation in legal metrology processes from standard-setting to verification is a good way to avoid future costs. If the firm's technology anticipates the norm, this firm won't have to incur additional costs to comply with the standard. In the producer maximisation program, this has to be included in future profits and again in the inter-temporal profit function that we will develop in the following section.

PRODUCTIVITY INCREASE

THE PRODUCTION FUNCTION

We have explained the mechanisms by which standards can improve productivity. In the Plasterboard case study **(Swann 2009)**, a better knowledge of raw product quality led to a more adequate use of the production process. To take this into account in our maximisation program, we assume that producers can now chose the production function $F(.)$ by deciding to adopt a standard or to buy more accurate equipment.

Now about the details of the production function. The economic literature uses a production function to model the transformation of inputs into outputs. The more general form is simply given by:

$$y = f(x_1, x_2, \dots, x_n)$$

Where $x_1, x_2, \dots, x_n$ are the different input quantities used. The production function gives the maximum production level obtained by the different combinations of production factors, with a given technology. Usually, two main kinds of inputs are considered: labour (L) and capital (K) and then

$$y = f(L, K)$$

Usually in economics, the production function is defined as a Cobb-Douglas function and takes the following form:

$$y = AK^{\alpha}L^{\beta}$$

Where A is a technology parameter, α and β are parameters for, respectively, capital and labour productivity. Their relation to one indicates the form of the returns to scale.

If $\alpha + \beta = 1$, returns to scale are constant,

If $\alpha + \beta > 1$, returns to scale are increasing,

If $\alpha + \beta < 1$, returns to scale are decreasing.

STANDARDS AND PRODUCTIVITY

In the examples we have described above, an improvement in measurement (due to standards or investment) means better inputs use (e.g. capital) meaning in turn that α increases. Similarly, standards adoption can improve labour quality (as it may be the case with management standards) and in turn increase the β parameter. The global productivity factor A can also be affected by conformity to legal metrology requirements. Indeed, this parameter reflects the efficiency of production techniques. When A increases, the combination of production factors is more effective (more can be produced with the same quantity). This parameter reflects technological progress.

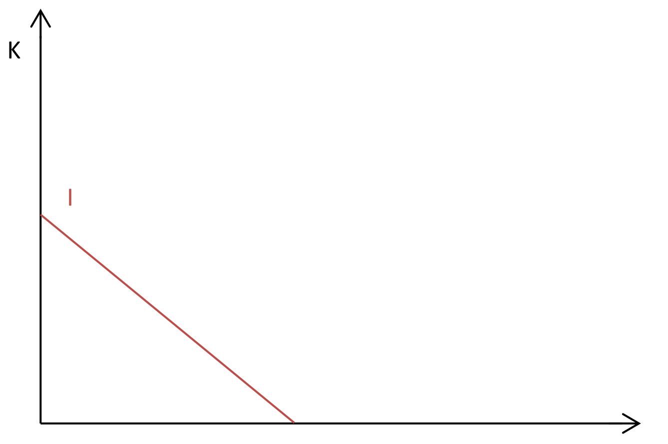


Figure 4 The isocost curve

The firm will use the production function and the cost function to determine the combination of inputs that will give the higher quantity of output, the total cost being kept constant. This can be represented graphically. In figure 3 the red line I represent the combination of capital and labour that can be used for the same total cost. The producer will want to use the one that gives the higher quantity of output.

The isoquant curves[5], Q_0, Q_1 and Q_2 (the blue curves in figure 4) are the combination of inputs, capital and labour, that produce the same quantity. The higher an isoquant curve is, the more quantity is produced. Hence in figure 4: $Q_0 < Q_1 < Q_2$. The producer will choose the combination of inputs, that belongs to his iso-cost curve and that allows him to have the highest quantity of output produced. On the graph, this would be the point where the iso-cost curve is tangent to one isoquant curve, here marked by a black cross. So for a given budget constraint (the iso-cost

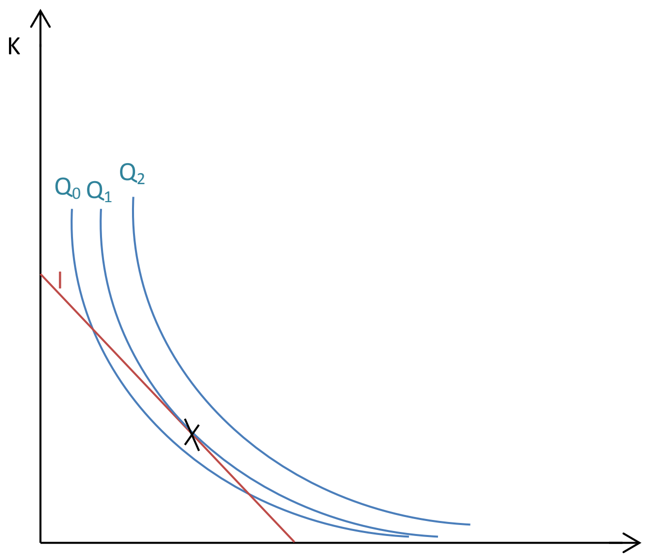


Figure 3 The isoquant curves

[5] There is an infinite number of isoquant curves; for simplicity and to facilitate the reading, we chose to only represent a few of them.

curve) this one will be the most efficient combination of inputs.

The parameters of the production function determine the isoquant curves. If one parameter of the function changes, the shapes of those curves will be altered. When α and β increase, the shape of the isoquants changes. When α increases, the isoquant curve changes as shown in figure 5: less capital is needed to obtain the quantity Q_0 with the same quantity of labour

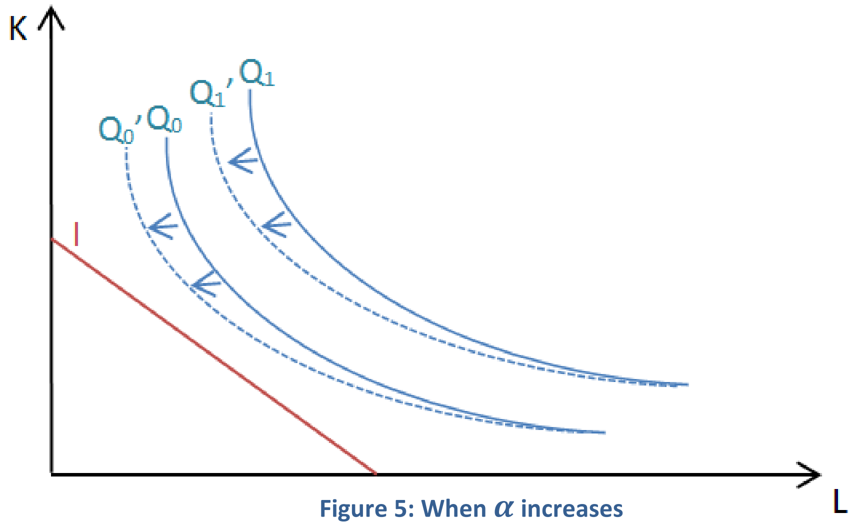


Figure 5: When α increases

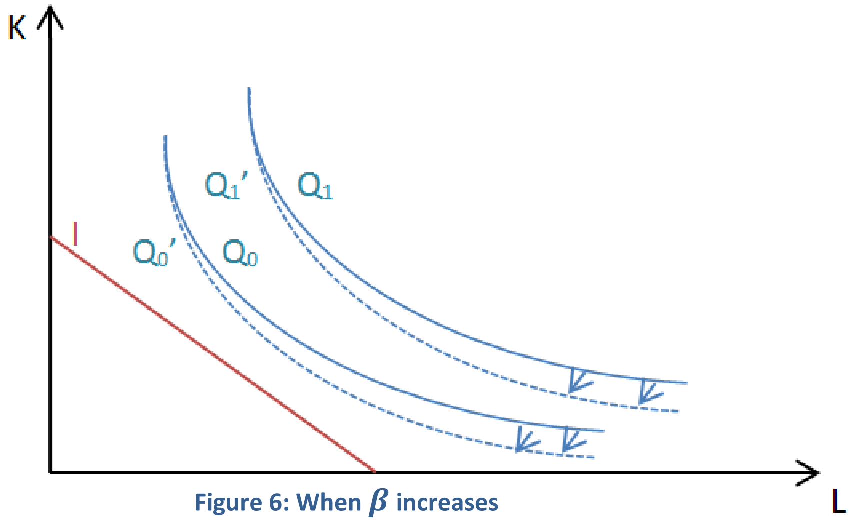


Figure 6: When β increases

When β increases, the isoquant curve changes as shown in Figure 6. Less labour is needed to produce the quantity $Q_0$with the same quantity of capital.

When A changes, the form of the isoquant remains the same but the curve is translated left and downwards, which means that we can produce more with the same combination of factors. Indeed, technological change allows for a more efficient use of production factors.

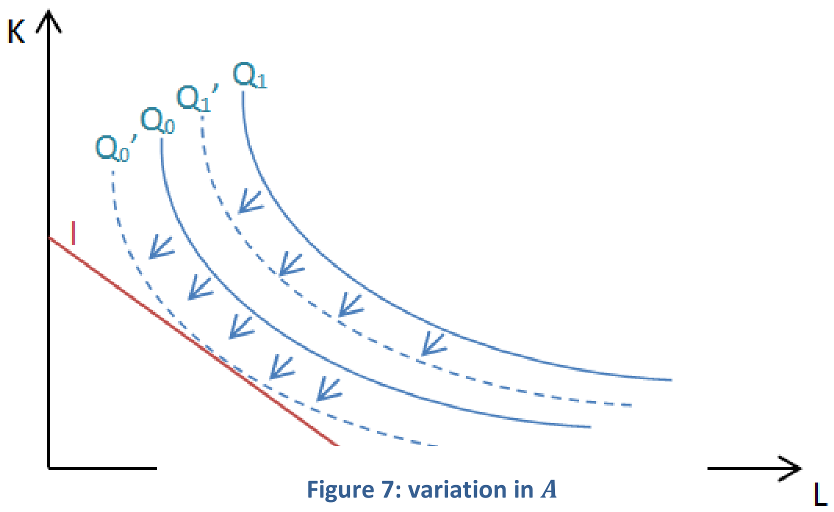


Figure 7: variation in A

All the parameters of the production function can be influenced by standard adoption or measurement improvement. A structural change in the combination of factors used in production could come from an improvement in equipment, leading in turn to a decrease in the proportion of labour used. This would mean an increase in productivity with a modification of the α parameter. The introduction of a new standard in management practices could increase the β parameter. Finally the adoption of a new technology could raise the parameter for global productivity, A. Since metrological requirements – and specifically harmonization in legal metrology – facilitate the development and the diffusion of innovations, we can assume that standards boost global productivity.

We have developed the functional form of the production function and underlined how standards and measurement improvement could influence its parameters. A change in these parameters A, α and β leads directly to an increase in profit through higher productivity.

$$\Pi' = p.F'^{(x)} - t_1.x - t_2 > \Pi = p.F(x) - t_1.x - t_2$$

$$F'(x) = A'K^{\alpha'}L^{\beta'}$$

$$x = (K, L)$$

Where at least one of the parameters α', β' and A' is different from its value before the improvement in conformity or the standard adoption.

PRICE INCREASE

We have explained the microeconomics foundations of the benefits legal metrology entails when considering the production and cost functions. Another channel through which conformity to standards bring gains to producers is the price. In a situation of perfect competition, producers are price-takers: they cannot influence prices. Modern microeconomics now considers different types of market configurations and examines situations where firms do influence the prices.

QUALITY INCREASE

The most obvious way by which firms can obtain a higher price for their products is an increase in their quality. Indeed, price can be defined as a function of the quality of the product (q) and others demand parameters (included in the z factor).

$$p = f(q, z)$$

We assume here that the price is an increasing function of the quality. We can imagine for example that the adoption of an environmental standard would guarantee a lower environmental impact, a quality valued by at least some consumers. Firms that enforce this standard can legitimately ask a higher price for it.

Another illustration is the Plasterboard case developed before. Because producers can adjust their production process to the quality and characteristics of the raw products, the quality of final product is eventually better. Thus:

$$p' = f(q', z) > \ p = f(q, z)$$

A higher price means a higher mark-up which is the difference between the cost of the good and its selling price.

QUALITY CERTAINTY

A higher price can only be applied if the higher quality is recognized by consumers, which is not certain in the absence of perfect information. Standards can then act as a signal for quality. Including this mechanism in our model implies we define price as a function of the quality, of the information available about the product (the parameter i) and other demand parameters:

$$p = f(q, i, z)$$

The use of publicly known standards increases the knowledge of consumers about the product which leads to a higher price:

$$p' = f(q, i', z) > \ p = f(q, i, z)$$

Indeed, as previously explained, better sampling methods can enhance the bargaining power of suppliers during the price-setting process. Facing a more accurate measure of the characteristics and quantity of the product, the buyer cannot pass on the cost induced by an uncertainty about the product onto the price.

In addition, the adoption of standards may allow producers access to new markets. Conformity to health, safety and quality standards, for example, may be necessary to sell on a regulated market, from food products to aeronautics. Adoption of standards could also be necessary to survive in a market facing a high supply shock such as the introduction of low-cost products. We illustrated this mechanism with the example of the steel fasteners market **(Haimowitz and Warren 2007)** where the INFASCO Company managed to survive the new competitive environment induced by the abundance of low-cost fastener from producers based in developing countries.

The increase in quality and information on the product generates a vertical differentiation of products on the same market. Vertical differentiation occurs when the different goods of a market differ from their quality. In the case of differentiation induced by new standards, the price can differ from the perfect competition price but the underlined mechanisms are different: a new variety arises from innovation, enhanced by standards. Then the producer of this new variety can benefit from a quasi-monopolistic position in this new market, at least in the short run.

In addition, with certification of quality, information asymmetries are reduced, decreasing the level of adverse selection. Then the average quality on the market increases because the average price is now higher. Our maximisation programme becomes:

$$\Pi' = p'.F'^{(x)} - t_1.x - t_2 > \ \Pi = p.F(x) - t_1.x - t_2$$

$$F'(x) = \ A'K^{\alpha'}L^{\beta'}$$

$$p' = p(q', i', z)$$

$$x = (K, L)$$

SOCIAL WELFARE

To understand the benefits brought by conformity to standards and metrological improvements, we need to consider the social welfare, *i.e.* the sum of consumers' surplus and producers' profit. We define W the global social welfare in a particular market.

$$W = \sum \Pi(\mathrm{p}, \mathrm{q}, \mathrm{t}_1, t_2, \alpha, \beta, A, x, i) \ + \sum U(p, x, q, i, n)$$

The profit parameters have already been defined. The price, quantity, quality and information also have an impact on the consumer's utility, as explained in Part III. The consumer's utility is thus represented by U, a function depending on the price, the quantity and quality of the product consumed. Additionally, the variety of products available, n, positively impacts their utility. Standard adoption and measurement improvement can thus increase social welfare as long as the cost of the standard implementation or conformity does not offset its benefits. We could add to this welfare function a cost parameter that would model the overall spending induced by the creation and implementation process of standard. This cost parameter is C_s in the following equation. Policy makers would thus have to maximise the following objective program:

$$W = \sum \Pi(\mathrm{p}, \mathrm{q}, \mathrm{t}_1, t_2, \alpha, \beta, A, x, i) \ + \sum U(p, x, q, i, n) - C_s$$

Here, we have not specified the repartition of the costs of the standards and legal metrology operations. A more complete model would describe the strategy of each economic agent and examine which actors bear which costs in conformity assessment, standardization or measurement traceability, for example.

Testing this theoretical model requires data on all the factors mentioned above. Since this data was not available at the time of the report we choose to focus on a specific feature of legal metrology: the definition and the harmonisation of the maximum permissible error of measuring instruments used for trade.

VII) CASE STUDIES: ASSESSING THE IMPACT OF THE MAXIMUM PERMISSIBLE ERROR REQUIREMENTS IN THE AUSTRALIAN WHEAT, COAL AND SUGAR INDUSTRIES

One of the most central aspects of legal metrology is defining reference procedures for measurements. As we saw before, a lot of efforts have been put into choosing and having all Parties agree to specific units of measurements. Maximum permissible errors (**MPE**) associated with these units have been defined by international metrology organisations such as the **OIML**.

In our cases, the product characteristics concerning quality and quantity are numerous and diverse. To simplify, we will consider only one of those features: weight. Legal metrology defines guidelines and methods of enforcement regarding weight measurement in transactions. When a producer sells his product to a buyer, these two Parties establish a contract defining the quantity traded (in our case, weight). Whenever the shipment doesn’t comply with the terms of the contract, it implies new costs. If the quantity delivered is superior to the one agreed on, the seller will suffer a loss proportionate to the surplus given for free. On the contrary, if the quantity delivered is inferior to the one agreed, the buyer may ask for compensation. Even more problematic, the seller’s reputation could suffer an intangible loss from this bad client experience.

Legal metrology defines maximum permissible errors for measuring instruments according to the nominal quantity to weigh. By doing so, legal metrology facilitates the act of contracting. The accuracy of the measurements depends on the quality of the measuring instruments used. This parameter is the first element we have to take into account. From this quality will follow the accuracy of the quantity sold.

SELECTING AN EXISTING MODEL AS A STARTING POINT

In order to quantify the economic impact of legal metrology we focus on one of its aspects only: the definition of the MPE. In the following, we develop a methodology for estimating the economic impact of having MPE fixed by regulations in the context of specific industries. Our starting point for this model is the very interesting article of T. Usuda and A. Henson **(Usuda and Henson 2012)**. Hence, we will begin with an explanation of their impact study.

The fundamental idea of the authors is that products are distributed according to their characteristics and quality. All products have to pass a conformity check before being sold. Producers determine the accepted quality interval with lower and upper testing limits. If the product belongs to this interval, it will be shipped to a client.

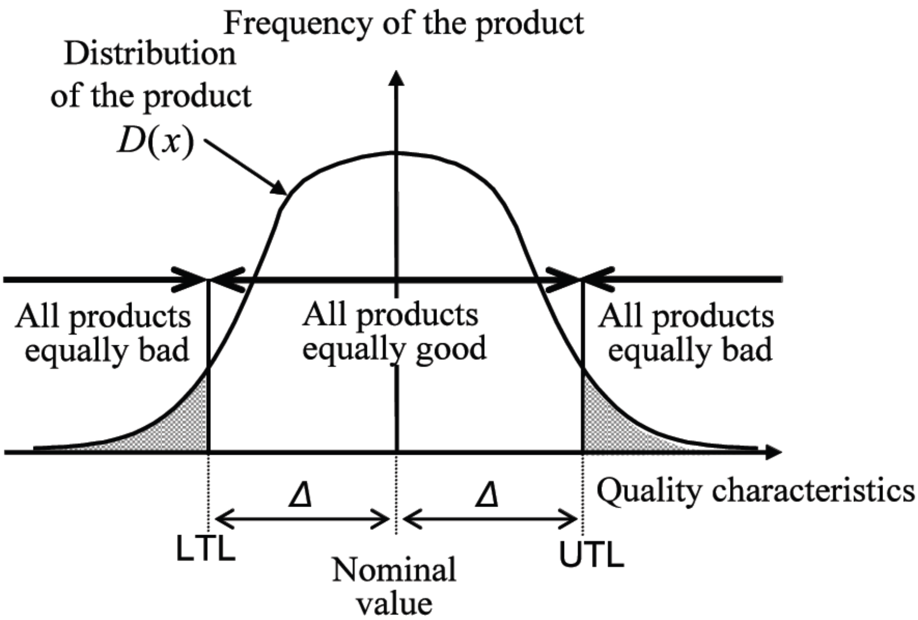


Figure 8: Conformity assessment. Source: (Usuda and Henson 2012)

In Figure 1 a normal distribution of the product quality is assumed. Lower and upper testing limits are represented respectively by LTL and ULT and the products that pass the conformity assessment are those that fall within the interval defined by those testing limits. In general, this interval is the result of negotiations between buyers and sellers. For instance, a miller selling his flour to a bakery has to establish a contract defining the quantity, price and frequency of the sales. This contract may take into account error measurements. Let's say the miller delivers a 50 kg bag of flour every two days. The contract may then indicate that every bag weighting between 49.8 kg and 50.2 kg complies with the contract conditions. In that case, the seller should calibrate his measuring instruments accordingly and make sure the measurement error doesn't exceed 0.2 kg. If the testing limit is not regulated by law, the seller will set it himself and face a trade-off between buyer satisfaction and production cost (more accuracy in measurement requires investment).

When the testing limit is not legally enforced, it may differ from sellers to buyers. Thus, in some cases, products that passed the seller's conformity assessment might not pass the one of the buyer (false positive). Symmetrically, some products that would have passed the buyer's conformity test won't be sold (and might be lost) because they weren't in the seller's conformity interval (false negative). This idea is represented in the following figure at three stages of an export/import transaction:

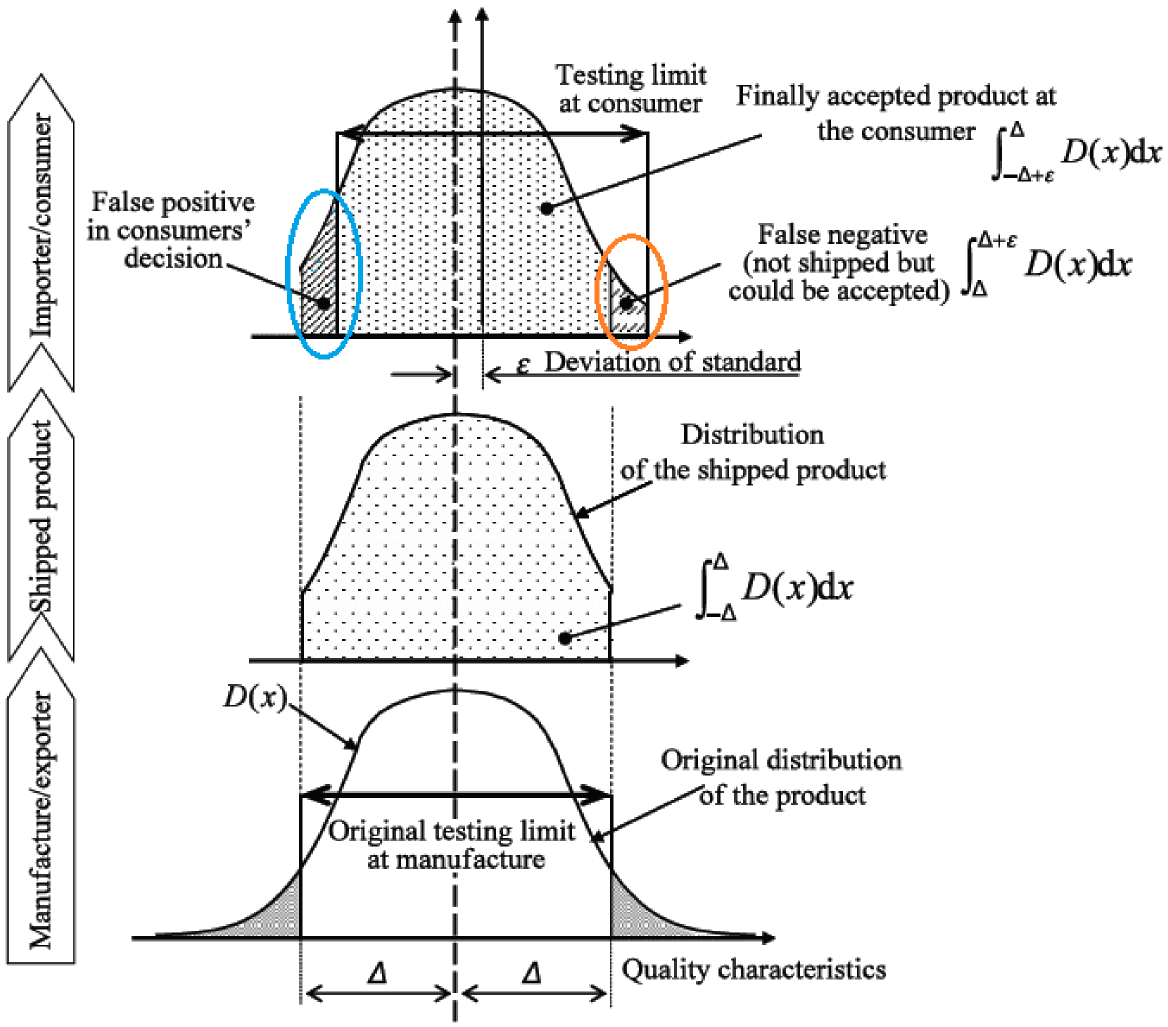


Figure 9: Additional loss due to deviation of measurement standards between an exporter and an importer. (Usuda and Henson 2012)

As described in Figure 8 a deviation ϵ in the measurement standard (for the buyer in the top part of the figure) causes false positive and false negative products. This results in additional costs. If we assume a normal distribution of the products over the quality characteristics, we need to take the integral under the distribution function as in the top part of the graph (respectively circled in orange and blue) in order to derive the percentages of false negatives and false positives. It is important to note that the proportion of false positives is higher than the proportion of false negatives. It means that the loss associated with false positives and false negatives are not equal. Here, the distribution function of the shipped product will be used to derive the costs associated with this difference in testing limits. Legal metrology, by harmonizing testing limits, helps preventing such cases where buyer's and seller's conformity assessments are markedly disparate. International coordination is crucial to avoid these types of divergence between importers and exporters.

The authors develop a methodology to derive the economic impact of the equivalence of measurement standards. They examine the industry of the analytical balance in Japan and assume that 99.9 % of the balanced produced passed the conformity test of the producers.

The conformity test used is the one defined by the OIML, stating that the masses used to check the accuracy of the balances must not be in error by more than one third of the maximum permissible error (**MPE**) of the instrument. The authors take the MPE of the 1 kg mass standard for the class F1 where the MPE is 5 mg. The mass used for the test must not be over or under 1.67 mg of the nominal value, 1 kg. Assuming that 99.9 % of the balances produced fall into the test limits defined by this conformity assessment, the distribution of the analytical balances produced is described in the following figure:

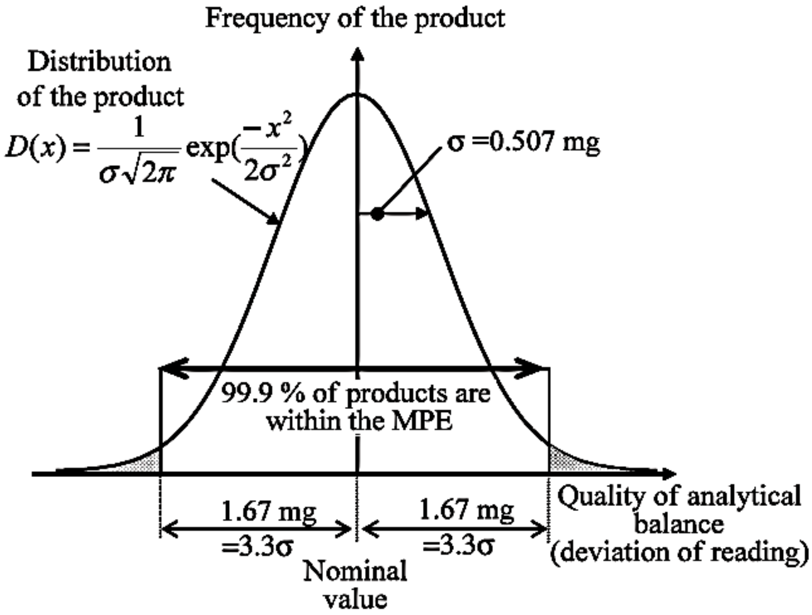


Figure 9 The distribution of analytical balances. (Usuda and Henson 2012)

The authors estimated that with the actual measurement uncertainty the Japanese balance industry only suffers a loss of ¥6.6 million, corresponding to less than 0.04 % of its annual turnover. With higher deviation of the metrology standard, Japan would suffer higher loss: for example with a deviation of 0.5 mg of the standards, the loss would be of ¥197 million (a little more than 1 % of annual turnover). In addition to this loss on the balance industry turnover, the loss in other industries due to the uncertainty over balance measurement can also be estimated. Usuda and Henson take the example of the platinum industry and postulate that the loss due to variation in MPEs is proportionate to the price per unit.

The economic impact of a deviation in standard for industries using this measure instrument is given by the following equation:

$$E_{impact} = \left|\int_{-\Delta-\epsilon}^{\Delta-\epsilon} \frac{D(x-\epsilon)}{Ntotal} T_{total} f(m-x)dx\right| - \left|\int_{-\Delta}^{\Delta} \frac{D(x)}{Ntotal} T_{total} f(m-x)dx\right|$$

Where ϵ is the deviation, $f(m-x)$is the loss function for a deviation of x compared to the aimed nominal value, 0. In addition T_{total} is the quantity of product in the industry (here the platinum industry). Finally the fraction $\frac{D(x)}{Ntotal}$ represents the proportion of balances with an error of x. This equation computes the proportion of false positive (due to the deviation) minus the proportion of false negative (due to the deviation). The false positive and false negative product multiplied by the economic loss they create. The following figure allows visualizing those proportions. In this figure, the economic impact is the grey shaded area of the top part of the figure, minus the grey shaded area of the bottom part of the figure:

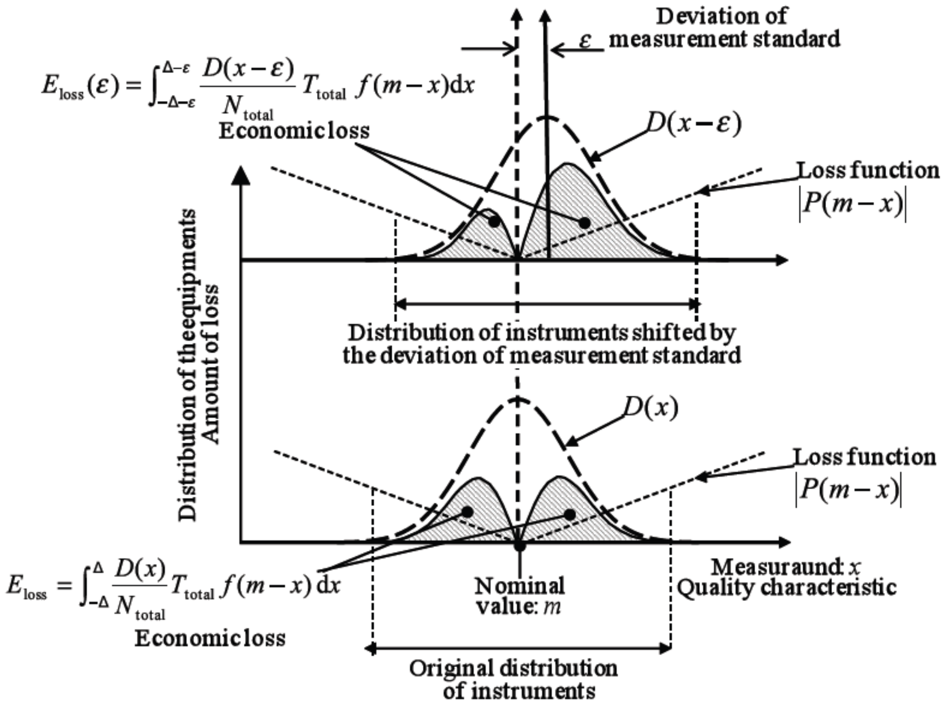


Figure 10 The loss associated with a deviation of measurement standards, assuming a normal distribution of the measuring instrument. (Usuda and Henson 2012)

One can observe that the loss with deviation of measurement standards is higher than if they are identical. So the economic impact associated with a deviation ϵ of the measurement standard depends on the additional fraction of products that results in false positives and false negatives compared to the situation without deviation.

In addition the loss function is assumed to be directly proportionate to the price per unit that is denoted by P in the following equation:

$$E_{impact} = \left| \int_{-\Delta-\epsilon}^{\Delta-\epsilon} \frac{D(x-\epsilon)}{Ntotal} T_{total} P.|m-x|dx \right| - \left| \int_{-\Delta}^{\Delta} \frac{D(x)}{Ntotal} T_{total} P.|m-x|dx \right|$$

When applied to the Japanese platinum industry, this method results in an estimated potential economic loss of USD228 600 dollars for a deviation of 0.5 mg. In the following section, we develop a similar model to show that legal metrology prevents similar economic loss for industries in Australia.

APPLICATION TO THE AUSTRALIAN WHEAT, SUGAR AND COAL INDUSTRIES

In this section we use the model developed by Usuda and Henson (Usuda and Henson 2012) as a starting point to estimate the economic loss induced by a divergence between the maximum permissible error in key Australian industries and their counterparts in importing countries. The main reason for using this model being that it is a better fit for the available data. Ultimately, the results attest of the need for international harmonization in legal metrology. We consider three sectors: sugar, coal and wheat. Those industries are of particular interest since Australia in 2012-2013 exported 68 % of its wheat production (22 million tons), 54 % of its coal (481 million tons mined) and 11 % of its sugar (30 million tons produced). Over such quantities in large-scale industries, small variations in the maximum permissible errors can lead to an economic impact definitely not negligible. The figures used in this section have been provided by the OIML.

We focus on import-export relations because variation of national metrology norms can lead to variation in the MPE. As we described above, deviations in the MPE from those used by the importer to those of the exporter, false positive and false negative errors in measurement can take place. In the case of weight, a false positive would consist in the shipment of a quantity lower than the one agreed on in the contract. The missing quantity would weight more than authorized by the MPE of the measuring instrument used by the importer. In that case, the exporter would have to compensate the importer financially. However, a false negative would be beneficial for the exporter since they would be able to ship less than previously arranged and still submit to the contractual conditions (see Fig. 2).

We will first reproduce the analysis developed by (Usuda and Henson 2012) by studying the economic impact of a divergence between the MPEs. We will then suggest a model that could estimate the economic impact of having higher or lower MPE in the measuring instrument used for trade. Those two estimations relate to the benefits of legal metrology since the MPEs are regulatory standards and their enforcement falls into the domain of legal metrology. The traded quantities we examine are weighted by weighbridges or belt conveyors. The legally authorized MPE are stipulated in the Australian National Trade Measurement Regulation [NMT Regs 1 Jan 2013 p134-148]. We will focus on exports from the three industries considered. The following tables summarize the information we have on those exports.

Table 1 Exports in the Sugar industry

Product	Price	Quantity	Measurements	MPE
Raw Sugar	$400/t	3 300 000 t	Weighbridge	0.1 %
Refined Sugar	$5/kg	500 000 t	Weighing instruments	0.1 %

Table 2 Exports in the Wheat industry

Product	Price	Quantity	Measurements	MPE
Bulk export	$400/t	15 000 000 t	Weighbridge	0.1 %
Manufactured export	$200/t	500 000 t	Weighing instruments	0.1 %

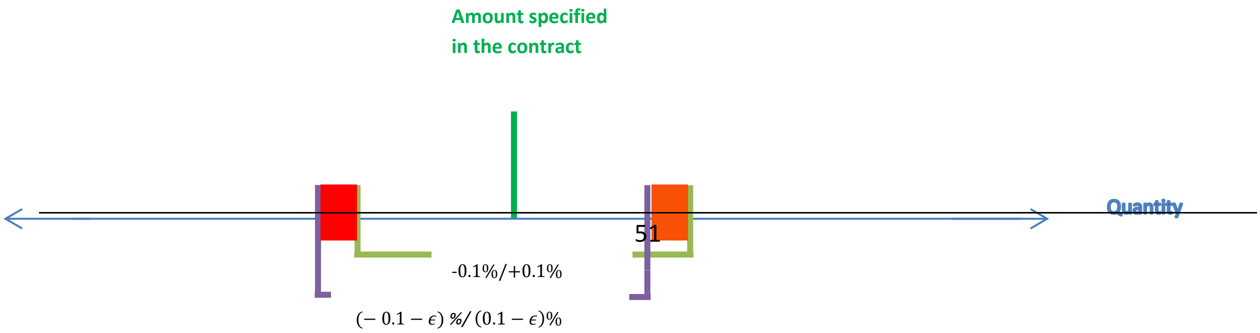
Table 3 Exports in the Coal industry

Product	Price	Quantity	Measurements	MPE
Coal	$85/t	261 000 000 t	Belt conveyor	0.5 %

CALCULATING THE ECONOMIC IMPACT OF DIVERGING MPE

We start with the sugar industry and will apply the same method to the other industries. Considering the quantity of raw sugar exported, the MPE is 0.1 % when using weighbridges. It implies that a measuring instrument with an accuracy of 0.1 % must be used for the transaction to happen. For a quantity of one tonne, the authorized margin of error is 1 kg. If we consider a quantity of one kg, the MPE would be +/- 1g. As did the authors in our base study, we estimate the economic impact of a difference in the MPEs of the seller and the buyer. The aim is to estimate the economic consequences of the importer and the exporter not having harmonized MPEs. The exporter could have a $-0.1\,\%/+0.1\,\%$ maximum permissible error and the importer a MPE of $(-\,0.1-\epsilon)\ \%/\,(0.1-\epsilon)\ \%$.

The following illustration represents this deviation (between purple and green intervals) and the false positives and negatives that ensue (respectively in red and orange).



As we mentioned before, false positives are associated with an economic loss for the exporter whereas false negatives constitute a gain. Therefore, in order to estimate the loss from MPE disparity we need to subtract the proportion of false negative to the proportion of false positive. We saw that, with a normal distribution of the instruments, those two proportions are not equal and the proportion of false positive tends to be bigger. The model built here allows estimating the economic impact of some legal metrology requirements. More precisely, it considers the economic benefits of fixing common MPE (and their enforcement modalities) for measurements instrument used for trade in exporting and importing countries.

The legal MPE for weighbridges is +/- 1 kg per tonne. Following (Usuda and Henson 2012), we consider that weighbridges, when built and inspected, are tested with masses of 1 ton for which the measure uncertainty is no more than one third of the MPE. We obtain a Δ that represent the possible measurement error of the weighbridge. So the quantity measured by the exporter will have an accuracy of +/- Δ, times the numbers of tons. If the importer has a deviation ϵ in his MPE compared to that of the exporter, then the economic impact of such deviation (the loss) will be:

$$E_{impact} = QP_{tonne}\left(\left|\int_{-\Delta-\epsilon}^{\Delta-\epsilon} D(x-\epsilon)\,.\,|0-x|dx\right| - \left|\int_{-\Delta}^{\Delta} D(x)\,|0-x|dx\right|\right)$$

This equation gives the proportion of false positive minus the proportion of false negative. We multiply the result by the quantity and by the price since we assume that the producer/exporter incurs a cost equal to the price for each false positive (and reciprocally a gain equal to the price for each false negative). The next table summarizes the result for the Sugar industry:

Table 4 Economic impact on the Australian Sugar industry of a deviation of the MPE

Product	Initial MPE	Deviation ϵ	Economic loss (AUD)
Raw Sugar	0.1 %/0.001tonne	0.01 %/0.0001tonne	14 129.11
Refined Sugar	0.1 %/0.001tonne	0.01 %/0.0001tonne	26 759.68
Total	0.1 %/0.001tonne	0.01 %/0.0001tonne	40 888.79

A small deviation between the Australian and the foreign MPEs (10 % of the Australian MPE) would cause AUD 40 888 of damages.

We apply exactly the same method on the Wheat Industry and derive an economic loss of AUD 65 293.

Table 5 Economic impact on the Australian Wheat industry of a deviation of the MPE

Product	Initial MPE	Deviation ϵ	Economic loss (AUD)
Bulk export	0.1 %/0.001 tonne	0.01 %/0.0001 tonne	64 223.23
Manufactured export	0.1 %/0.001 tonne	0.01 %/0.0001 tonne	1 070.387
Total	0.1 %/0.0005 tonne	0.01 %/0.0001 tonne	65 293.62

The method is similar in the Coal industry but since it is not the same measuring instrument that is used, the initial MPE is not the same. The larger MPE results in a higher economic loss: indeed a deviation of 10 % of the initial MPE would lead to an economic loss of more than one million of Australian dollars.

Table 6 Economic impact on the Australian Coal industry of a deviation of the MPE

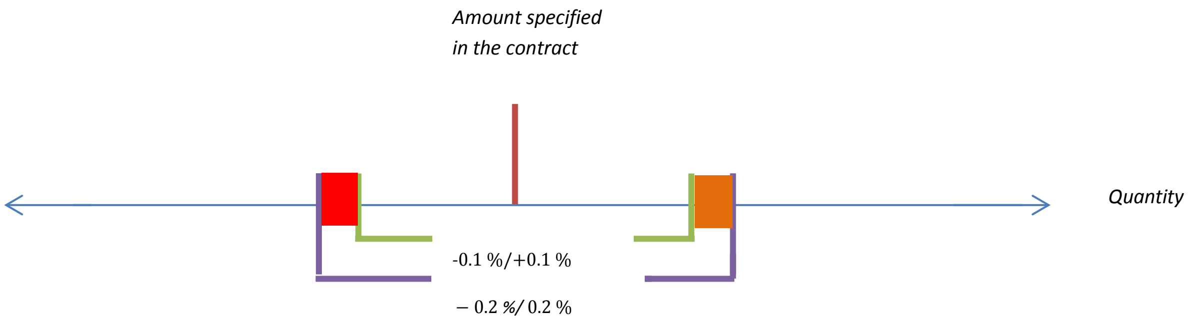
Product	Initial MPE	Deviation ϵ	Economic loss (AUD)
Coal	0.5 %/0.005 tonne	0.05 %/0.0005 tonne	1 187 327

The economic impacts that we estimated were caused by a deviation of the testing limits between the exporter (Australia) and the importer (rest of the world). This deviation can be expressed as a geometric translation of the testing interval to the right. We now consider the case when it is the amplitude of the MPEs that differs: for example if the Australian economy had a larger MPE interval than the rest of the world.

ECONOMIC IMPACT OF A LARGER PERMISSIBLE ERROR INTERVAL

Legal metrology produces rules and enforcement dispositions to maintain a uniform measurement system nation-wide. In Australia, the National Trade Measurement legislation [NTP Regs 1] defines the characteristics weighbridges and belt conveyors must possess in order to be used in trade measurement. The penalties for non-conformity to these rules are stipulated as well. The measurement infrastructure and more specifically the legal requirements on the accuracy of the measuring instruments used for trade are also defined so as to benefit international trade, notably by eliminating technical barriers to trade.

To further analyse the economic benefits of legal metrology, we will now turn to the benefit of having a given MPE value enforced by legal metrology authorities. We assume that the Australian MPE used for trade in Sugar and Wheat transactions is 0.2 % (so twice the current value) and that the one used by the importers is 0.1 %. This gap may come, in our hypothetical case, from lack of enforcement for more accurate weighting devices in Australia. The difference in MPEs is described in the following figure where the green lines represent the importers MPE and the violet line the Australian MPE:



The red area in the figure represents false positive but the orange one is yet another type of false positive: the act of sending more quantity than needed. This second type of false positive is also a loss for the producer since their MPE leads them to send more than sold. To derive the loss they suffer due to this larger MPE we now need to compute the sum of the two false positives.

Indeed the Australian Industry will suffer losses from both types: there will be cases where the quantity weighed will be in accordance to the contract when weighted on an Australian weight instrument but will be revealed to be not in accordance to the contract when weighted on international weight instruments (due to the different MPEs). The red area represents the cases where the quantity weighted on Australian instruments was found to be conforming to the contract but international weighing instruments revealed that there was not a sufficient amount, meaning that the exporter would have to give monetary compensation to the importer since the quantity defined in the contract was not achieved. The orange area in the figure represents the case where a more accurate weigh instrument would have allowed the exporter to send a lesser amount that would still have conformed to the contract. The difference between the amount actually sent and the lesser amount that could have been sent with more accurate instruments is a loss for the exporter (he gave free quantities to the importer).

The equation determining the economic loss associated with a less accurate MPE is:

$$E_{impact} = QP_{tonne}\left(\left|\int_{-\Delta-\epsilon}^{\Delta+\epsilon} D(x)\,.\,|0-x|dx\right| - \left|\int_{-\Delta}^{\Delta} D(x)\,|0-x|dx\right|\right)$$

It corresponds to the proportion of quantity falling in the orange or red area in the illustration. This proportion of quantity sold is then multiplied by the price and the total quantity.

Table 7 Economic impact of a less accurate MPE on the Australian Sugar industry

Product	Australian MPE	Importer MPE	Economic loss (AUD)
Raw Sugar	0.2 %/0.002 tonne	0.1 %/0.001 tonne	105 925.3
Refined Sugar	0.2 %/0.002 tonne	0.1 %/0.001 tonne	200 616
Total	0.2 %/0.002 tonne	0.1 %/0.001 tonne	306 541.3

The economic impact of a less accurate MPE has to be taken into account since a slightly larger MPE entails a loss of AUD 306 541 for the Australian Sugar industry.

On the Wheat industry:

Table 8 Economic impact of a less accurate MPE on the Australian Wheat industry

Product	Australian MPE	Importer MPE	Economic loss (AUD)
Bulk export	0.2 %/0.001 tonne	0.1 %/0.001 tonne	481 478.4
Manufactured export	0.2 %/0.001 tonne	0.1 %/0.001 tonne	8 024.641
Total	0.2 %/0.001 tonne	0.1 %/0.001 tonne	489 503.1

The impact of a less accurate MPE is superior to the effect of a unilateral deviation in the MPEs. We estimate that AUD 489 503 would be lost each year for the Wheat industry if the Australian measurement infrastructure was not as accurate as it currently is (In reality it is of 0.05 %).

Finally, if we consider the Coal industry, the impact becomes considerable:

Table 9 Economic impact of a less accurate MPE on the Australian Coal industry

Product	Australia MPE	Importer MPE	Economic loss (AUD)
Bulk export	1 %/0.01 tonne	0.5 %/0.005 tonne	8 901 333

The annual impact would be around an annual AUD 9 million for the Coal industry. The annual impact on all the industries combined is AUD 9 697 377,4.

CONCLUSION

The goal of this report was to review the literature on the economics of metrology and standards and provide elements for modelling the economic benefits of legal metrology. Macroeconomics benefits – to growth, productivity and innovation – are identified, as well as a way to assess the benefits of legal metrology activities – testing, verification, and international harmonization. But as we learned from the history of legal metrology, it expanded from its original applications in science and industry and now forms the backbone of domestic and international trade, as well as a powerful channel connecting policy and trade. The benefits of legal metrology have to be approached by multiple angles.

From a policy standpoint, it is clear that investing in legal metrology research, enforcement and infrastructure impacts growth positively. From the customer perspective as well, since legal metrology requirements provide certainty in quality and safety along with an increased choice of products. Evidently, the benefits of metrology for producers are plenty, but those entailed by legal metrology regulation have been under less scrutiny. They are thought to be substantial, as our model indicates, and rely to a large extend on the international harmonization of legal metrology standards. It would now be interesting to extend our theoretical model and test it with the appropriate data. Another improvement would be to include the costs induced by legal metrology spending in this model.

The fundamental benefit of legal metrology is that it is a network technology in itself. When enforced homogeneously on a market or territory, it accelerates and simplifies commercial transactions, all Parties benefitting from more comparability, traceability and trust. It is no wonder legal metrology was both a product and a precursor of the industrial revolutions of the past centuries. Faced with new advances in technology but also new challenges posed by globalization and the threat of environmental collapse, legal metrology is continuously adapting.

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APPENDIX: R CODE

```
###Assumptions concerning weightbridge distribution ###
#We make the same assumptions of balance distribution as Usuda:
#First we assume that weight of 1t of class M3 are used. MPE for those: 1 000 000 mg so 1 kg
#As in Usuda, we assume 1/3 of MPE + Normal distribution
MPE = 0.001
delta = MPE/3
# We assume Npass, as in Usuda = 0.999Ntotal
sigma = delta/3.3
sigma
### The Wheat industry in Australia ###
### Exports
###Bulk exports
P1t = 400
Q = 15000000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # # # # # # Loss with deviation # # # # # # #
epsilon1 = MPE/10
f2<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-((x-epsilon1)^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta -epsilon1,delta -epsilon1)
y2
loss1 = y2[[1]] - y1[[1]]
loss1
#So we would have a loss of 64 223.23 dollars over the whole economy
###Manufactured export
P1t = 200
Q = 500000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # # # # # # Loss with deviation # # # # # # #
epsilon1 = MPE/10
f2<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-((x-epsilon1)^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta -epsilon1,delta -epsilon1)
loss2 = y2[[1]] - y1[[1]]
loss2
loss1 + loss2
```

```
### MPE of higher magnitude ###
### Bulk export
P1t = 400
Q = 15000000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # Loss due to the higher MPE
MPE2 = 2*MPE
delta2 = MPE2/3
sigma2 = delta2/3.3
f2<-function(x){
out<- Q*(1/(sigma2*sqrt(2*pi)))*exp((-((x)^2))/(2*(sigma2^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta2,delta2)
y2
loss = y2[[1]] - y1[[1]]
loss
### Manufactured exports
P1t = 200
Q = 500000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # # # # # Loss due to the higher MPE
MPE2 = 2*MPE
delta2 = MPE2/3
sigma2 = delta2/3.3
f2<-function(x){
out<- Q*(1/(sigma2*sqrt(2*pi)))*exp((-((x)^2))/(2*(sigma2^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta2,delta2)
loss1 = y2[[1]] - y1[[1]]
loss1 + loss
### The Sugar industry in Australia ###
### Exports of raw sugar
P1t = 400
Q = 3300000


f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
```

```
y1 = integrate(f1,-delta,delta)
y1
# # # # # # # #  Loss with deviation # # # # # # #
epsilon1 = MPE/10
f2<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-((x-epsilon1)^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta -epsilon1,delta -epsilon1)
loss = y2[[1]] - y1[[1]]
loss
### Exports of refined sugar
P1t = 5000
Q = 500000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # # # # # #  Loss with deviation
epsilon1 = MPE/10
f2<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-((x-epsilon1)^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta -epsilon1,delta -epsilon1)
loss1 = y2[[1]] - y1[[1]]
loss1
loss1 + loss
### MPE of higher magnitude ###
P1t = 400
Q = 3300000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # Loss due to the higher MPE
MPE2 = 2*MPE
delta2 = MPE2/3
sigma2 = delta2/3.3
f2<-function(x){
out<- Q*(1/(sigma2*sqrt(2*pi)))*exp((-((x)^2))/(2*(sigma2^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta2,delta2)
y2
loss = y2[[1]] - y1[[1]]
loss
# refined sugar
P1t = 5000
```

```
Q = 500000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
# # # Loss due to the higher MPE
MPE2 = 2*MPE
delta2 = MPE2/3
sigma2 = delta2/3.3
f2<-function(x){
out<- Q*(1/(sigma2*sqrt(2*pi)))*exp((-((x)^2))/(2*(sigma2^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta2,delta2)
y2
loss1 = y2[[1]] - y1[[1]]
loss1 + loss
### Coal industry ###
#Not the same permissible error than in the other industries
MPE = 0.005
delta = MPE/3
# We assume Npass, as in Usuda = 0.999Ntotal
sigma = delta/3.3
sigma
P1t = 85
Q = 261000000
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
# # # # # # # #  Loss with deviation
epsilon1 = MPE/10
f2<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-((x-epsilon1)^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta -epsilon1,delta -epsilon1)
y2
loss = y2[[1]] - y1[[1]]
loss



### MPE of higher magnitude ###
f1<-function(x){
out<- Q*(1/(sigma*sqrt(2*pi)))*exp((-(x^2))/(2*(sigma^2)))*P1t*abs(0-x)
return(out)
}
y1 = integrate(f1,-delta,delta)
y1
# # # Loss due to the higher MPE
```

```
MPE2 = 2*MPE
delta2 = MPE2/3
sigma2 = delta2/3.3
f2<-function(x){
out<- Q*(1/(sigma2*sqrt(2*pi)))*exp((-((x)^2))/(2*(sigma2^2)))*P1t*abs(0-x)
return(out)
}
y2 = integrate(f2,-delta2,delta2)
y2
loss = y2[[1]] - y1[[1]]
loss
```