Deloitte.

platform wiskunde nederland

Mathematical sciences and their value for the Dutch economy

January 2014

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Executive summary

"Platform Wiskunde Nederland" is the organisation that represents the Dutch mathematics community. Its mission is to enhance the financial, managerial, scientific and public position of mathematics in the Netherlands. To better understand the contribution of mathematical sciences to the Dutch economy, the board of PWN has requested Deloitte to assess the economic impact of mathematics on the Dutch economy.

The full time equivalent of about 900,000 highly educated employees use mathematical sciences in the Netherlands. They include scientists who use mathematics all the time, as well as bankers, who spend some of their time computing the value of assets, and physicians, who use maths to interpret medical tests.

These 900,000 jobs not only generate direct income for the employees involved. People who work in industries that supply organizations where mathematical sciences practitioners work and in businesses where these practitioners spend their own income benefit as well. Based on standard input-output analyses of the Dutch economy, these so-called indirect and induced effects are estimated to create another 1.4 million jobs, resulting in mathematical sciences contributing for up to 26% to total employment. Because these are high income jobs, the economic contribution of mathematical sciences is even higher, representing around 30% of Dutch national income.

More fundamentally, a strong mathematical sciences foundation is critical to the success of any advanced economy. Better mathematical skills correlate with a more competitive economy and a higher standard of living. Moreover, with the revolutions in computational science, big data, statistics and business analytics the importance of mathematical sciences to society is likely to increase substantially in the coming decades. These revolutions are driven by ever more powerful computers, the data explosion, and improved algorithms.

The Netherlands risks missing out on these trends and losing its competitiveness as a nation, because the number of science and engineering graduates has dropped to the lowest level in Europe. At current graduation rates, 400,000 direct, indirect and induced jobs - 5% of the Dutch workforce - would disappear. Conversely, just bringing the number of mathematical jobs to current UK levels, would create about 700,000 jobs. A solid basic mathematical understanding will thus be critical for the continuing economic success of the Netherlands.

This is the moment to seize the opportunities. More and better usage of mathematical sciences will enable the Netherlands to retain its position as one of the most competitive countries in the world and maintain its high standard of living.

Samenvatting

Platform Wiskunde Nederland (PWN) is de organisatie die de wiskundige beroepsgroep, in zeer brede zin, in Nederland vertegenwoordigt. Belangrijke doelen zijn het versterken van de financiële, bestuurlijke, wetenschappelijke en publicitaire positie van de wiskunde, statistiek en besliskunde in Nederland. Om een beter beeld te krijgen van de bijdrage van wiskunde, statistiek en besliskunde aan de economie, heeft het PWN Deloitte gevraagd om de waarde van wiskunde voor de Nederlandse economie in kaart te brengen.

Het blijkt dat het equivalent van 900.000 hoger opgeleide Nederlanders wiskunde, statistiek en besliskunde gebruikt in hun dagelijks werk. Zij variëren van wetenschappers die doorlopend met wiskunde bezig zijn, tot bankiers die wiskunde een deel van hun tijd gebruiken, bij voorbeeld om activa te waarderen, en artsen die soms wiskunde nodig hebben om de resultaten van medische onderzoeken te kunnen interpreteren.

Deze 900.000 banen genereren niet alleen inkomsten voor de betrokkenen zelf, maar ook bij bedrijven die producten of diensten leveren aan de gebruikers van wiskunde of aan de organisaties waar zij werken. Een standaard input-output analyse van de Nederlandse economie indiceert dat deze zogenaamde indirecte en afgeleide effecten nog eens 1,4 miljoen additionele banen opleveren. Daarmee dragen gebruikers van wiskunde, statistiek en besliskunde bij aan een kwart van de Nederlandse werkgelegenheid en, omdat zij relatief goed betaald worden, aan circa 30% van het bruto nationaal product.

Verder blijkt dat wiskundige kennis sterk correleert met de internationale concurrentiekracht van een land. Een goede basis in wiskunde, statistiek en besliskunde is een belangrijke pijler onder het succes van de Nederlandse economie. Met de explosieve toename van data, onder andere door het internet, met steeds snellere computers en met betere rekenmethodes zal het belang van deze pijler de komende jaren alleen maar toenemen.

Nederland loopt echter de kans hier de boot te missen omdat het aantal afstudeerders van de bètafaculteiten is gedaald tot het laagste niveau binnen Europa. Als deze trend zich voortzet, zouden 400.000 banen - 5% van de arbeids populatie - die in directe, indirecte of afgeleide zin afhankelijk zijn van wiskunde, kunnen verdwijnen. Omgekeerd zou groei van het aantal wiskundige banen naar het huidige niveau van het Verenigd Koninkrijk al 700.000 banen opleveren. Een goede basis in wiskunde is dus essentieel voor een succesvolle Nederlandse economie.

Er zijn zeker kansen. Meer en beter gebruik van wiskunde zorgt ervoor dat Nederland zijn positie als een van de meest competetieve landen ter wereld kan behouden en dat ons welvaartspeil onverminderd hoog blijft.

1. PWN wants to understand the economic impact of mathematics

The organization "Platform Wiskunde Nederland" (PWN) represents the Dutch mathematics community.

It was founded in 2010 by the Royal Mathematical Society (Koninklijk Wiskundig Genootschap, KWG) and the Dutch Association of Mathematics Teachers (Nederlandse Vereniging van Wiskundeleraren, NVvW) to enhance the financial, managerial, scientific and public position of mathematics in the Netherlands and to enable better mathematical research. To this end PWN has set up five committees: (1) Education, (2) Research, (3) Innovation, (4) Publications and (5) Publicity.

To better understand the contribution of mathematical sciences to the Dutch economy, the board of PWN has requested Deloitte to assess the economic impact of mathematics on the Dutch economy. In 2012, Deloitte already conducted a similar study for the United Kingdom, commissioned by the Engineering and Physical Sciences Research Council (EPSRC) and the Council for the Mathematical Sciences (CMS).

Although most people use basic mathematics every day, this report focusses on the more complex usage of mathematics. This would include methods and tools for financial processes or for predictions of construction strength. We call this 'mathematical sciences' (see the insert on this page).

Mathematical sciences
Mathematical sciences are the result of high-end research in mathematics, statistics and operations research carried out by academic institutions, research centres, businesses, individuals and government, which all add to the store of accumulated mathematical knowledge. Mathematical sciences occupations either use or develop mathematical sciences and derived methods, tools and techniques. Although employees with a middle or lower education also use mathematics, statistics and operations research in their daily lives, only people in jobs requiring a higher education are considered potential users of mathematical sciences in this report.

We have assessed the impact of mathematical sciences on the Dutch economy through five consecutive steps (see figure 1):

- First, we identified which jobs use mathematical sciences and to what extent (mathematical sciences intensity of a job).
- We then used these data to calculate the mathematical sciences intensity for each industry, as defined by Statistics Netherlands ("Centraal Bureau voor de Statistiek", or CBS) through a 'jobs to industries' matrix.
- We subsequently produced a list stating the 'mathematical sciences jobs' per industry and their corresponding added value, the so called direct effect
- To understand 'indirect' effects, the economic impact of mathematical sciences jobs on other industries - e.g. through purchases of goods by companies with mathematical sciences jobs we used the standard CBS input-output table of the Dutch economy. This table also allowed us to calculate the 'induced' effect, which measures the impact of consumer purchases by people in directly and indirectly affected jobs.
- Finally, by adding the direct, indirect and induced effects we were able to determine the economic contribution of mathematical sciences to the Dutch economy.

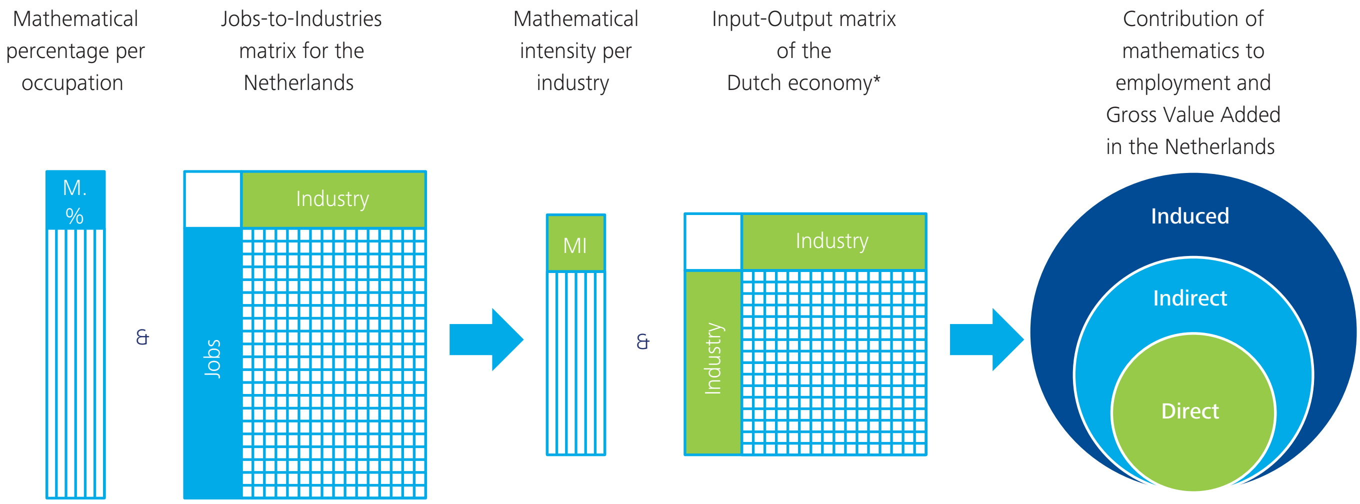
Although based on standard techniques, this approach has a number of limitations.

- First, the mathematical sciences intensities we used per job are only estimates: these data are not available from other sources. In reality they could be lower or higher than estimated.
- Second, in calculating the direct effects on employment, we excluded all employees without a college or university (HBO or Universiteit) degree. This may lead to the effects being underestimated.
- The input–output tables that we used to calculate the indirect and induced effects, assume the input proportions between different economic sectors to be fixed and to not change significantly in the short term. This could result in overstated outcomes, as effects tend to diminish as inputs get larger.
- Finally, we did not take into account any economic benefits from commonly used products and technologies that heavily rely on mathematics. Examples are usage by the wider public of the internet and mobile phones, both of which need advanced mathematical algorithms to function. In this sense our approach substantially understates the benefits of mathematical sciences to society.

Of course, many jobs require multiple capabilities concurrently. People that use mathematical sciences will also use languages and social skills. This means that, when used to assess the impact of all these skills, our approach would yield results that add up to more than 100% of the economy, Notwithstanding, a high percentage implies high importance.

These limitations need to be taken into account when interpreting the outcomes of this study.

Figure 1. Methodology overview



* Appendix D includes a detailed description of the input-output technique

This report details these analyses in the next two chapters. Chapter two describes the mathematical intensity of the Dutch economy by identifying the number of mathematical sciences jobs by industry. Chapter three then assesses the economic impact of these jobs through input-output analyses.
In chapter four we will put these findings in a wider perspective and discuss the potential contribution of mathematical sciences to economic development. Finally, chapter five looks at the relation between the number of mathematically trained employees in the Netherlands and economic growth.

To prepare this report we have cooperated with a steering committee consisting of:

- Prof. dr. W.H.A. Schilders, managing director Platform Wiskunde Nederland and professor of Scientific Computing, TU Eindhoven,
- Prof. dr. J.K. Lenstra, fellow at CWI (Centrum Wiskunde & Informatica, the National Research Institute for Mathematics and Computer Science in the Netherlands) and Chairman of the Writing Group, Platform Wiskunde Nederland; and
- Drs. F.A. Roos, executive officer at CWI and secretary of the Writing Group, Platform Wiskunde Nederland.

2. Almost a million Dutch employees use mathematical sciences

Mathematical tools and mathematical thinking are widely used in the Netherlands in technical, social and economic sciences too. The fruits of these sciences affect the daily lives of everyone in the Netherlands.

- Techniques from mathematics, statistics and operations research have led to a saving of € 4.3bn in a recent project on optimal dike heights, and the minister has adopted the proposed approach. The project, named 'Economically Efficient Flood Standards to Protect the Netherlands against Flooding', has also won the prestigious international Franz Edelman Award.
- The application of contemporary mathematical research can be seen in personal navigation systems like the ones developed by TomTom. They calculate the shortest routes between two places in a network and use an algorithm developed by Dutch mathematician Edsger Dijkstra to do so, as well as many recently developed methods.
- Smart phones, too, use mathematical techniques such as linear algebra to maximize the output of information that can be transmitted across a limited spectrum. This also holds for the chips of NXP Semiconductors that are contained in these smart phones.
- Train schedules are extremely complicated, and are planned and optimized using sophisticated mathematical techniques developed at the CWI in Amsterdam.
- ASML, the global leader in equipment for chip manufacturing, uses a multitude of techniques from mathematics, statistics and operations research to design and produce their machines. Being at the forefront of what is possible nowadays, the pressure on efficient and sound computational techniques is enormous.
- Mathematical sciences are indispensable in the area of health. Examples are imaging techniques in CT and MRI as developed by Philips, and the reduction of waiting times in hospitals from 3 weeks to 2 days as realized recently by Twente University.

Next to consumers of mathematics, many occupations in the Netherlands require the use of mathematical sciences research or the use of mathematical sciences research-derived tools and techniques for most or part of their daily work routines. These practitioners generally use mathematics to:

- Make sense of data and better understand the world.
- Safeguard society.
- Forecast and address uncertainty.
- Optimize processes.

Making sense of data and better understanding the world is one of the classic ways in which mathematics plays a role in the economy through the processing and understanding of raw data. At the most fundamental level this may involve civil engineers who apply differential calculus in stress calculations and managers who use mathematical principles for areas like calculating growth rates, financial analyses, market sizing and pricing.

More advanced examples are physicians who use imaging techniques that rely on differential geometry to quickly spot tissue anomalies in hundreds of MRI images, and coaches of Dutch athletes at the 2012 Olympic Games who maximized performances using tools that harness mathematical tools and techniques such as inverse dynamics. With the size of datasets increasing, mathematical algorithms are being increasingly used in making sense of data to uncover patterns and chart relationships.

Mathematics has an economic impact too, through its contribution to *security*. The pharmaceutical sector, for instance, applies mathematics to better understand results from clinical trials for new drugs. Many Dutch cyber-security companies provide products and services for defensive and offensive applications across IT, telecoms, banking and industrial equipment – all areas where mathematics plays a key role.

"Many occupations require the use of mathematical sciences for most or part of their daily work routines"

Mathematical models have to be used to *address uncertainty* and allow businesses and policy makers to plan ahead through the use of *forecasts*. Mathematical risk models are widely used in a number of sectors in the economy, including insurance, pensions, finance, individualized risk assessments for heart attacks, health policies for epidemics, weather and climate and the associated hazards of flooding.

Examples of occupations in this area are management consultants who use data mining to analyse enormous quantities of data to spot patterns and to understand operational processes in large corporations, and analysts at oil companies who use Monte Carlo simulation to stress test investment decisions. Meteorologists use mathematical models, based on differential equations and statistical analysis, to predict the movement of weather systems. Also, bankers use mathematics to value companies and securities, with techniques ranging from relatively straightforward Excel sheets to advanced analytical and stochastic models.

Mathematics is also used to *optimize processes*. Operations research techniques are frequently used across a number of industries to optimize processes and maximize value-for-money. Think of optimizing production schedules, locating distribution centres and defining trucking routes.

One example regards Schiphol Airport operators who apply mathematical principles from graph and queuing theory to move luggage from the drop-off point to the airplane and back. Planners at logistical companies like PostNL and Federal Express use mathematical models to optimize the routing of delivery vans. Also, every day, managers of oil refineries interpret the results of linear programming models that take into account expected volumes and prices of oil and end products to suggest what to manufacture.

As the wide range of mathematical applications suggests, practitioners of mathematics can be found throughout the Dutch economy across a wide range of jobs.

We used CBS data to establish the number of mathematical sciences jobs. The data provides for 1211 categories to define all jobs in the Netherlands. For each of these we assessed their 'mathematical sciences intensity': the fraction of time relying or spent on mathematical sciences. We used the percentages by occupation from our earlier UK study. These are based on interviews with job market experts and validation sessions with several expert committees. Because the CBS cannot provide the same level of detail as its UK counterpart, we have used the arithmetic mean of the underlying UK occupations to determine the percentage for each Dutch class of occupation. Appendix A includes the complete list.

We can infer from this list that 1.3 million of the 8.7 million employees in the Netherlands use some form of mathematical sciences. Weighted by the intensity of usage, this translates into 0.9 million jobs. These 0.9 million - more specifically 928,000 - jobs correspond to 11% of total employment and 35% of higher education employment in the Netherlands.

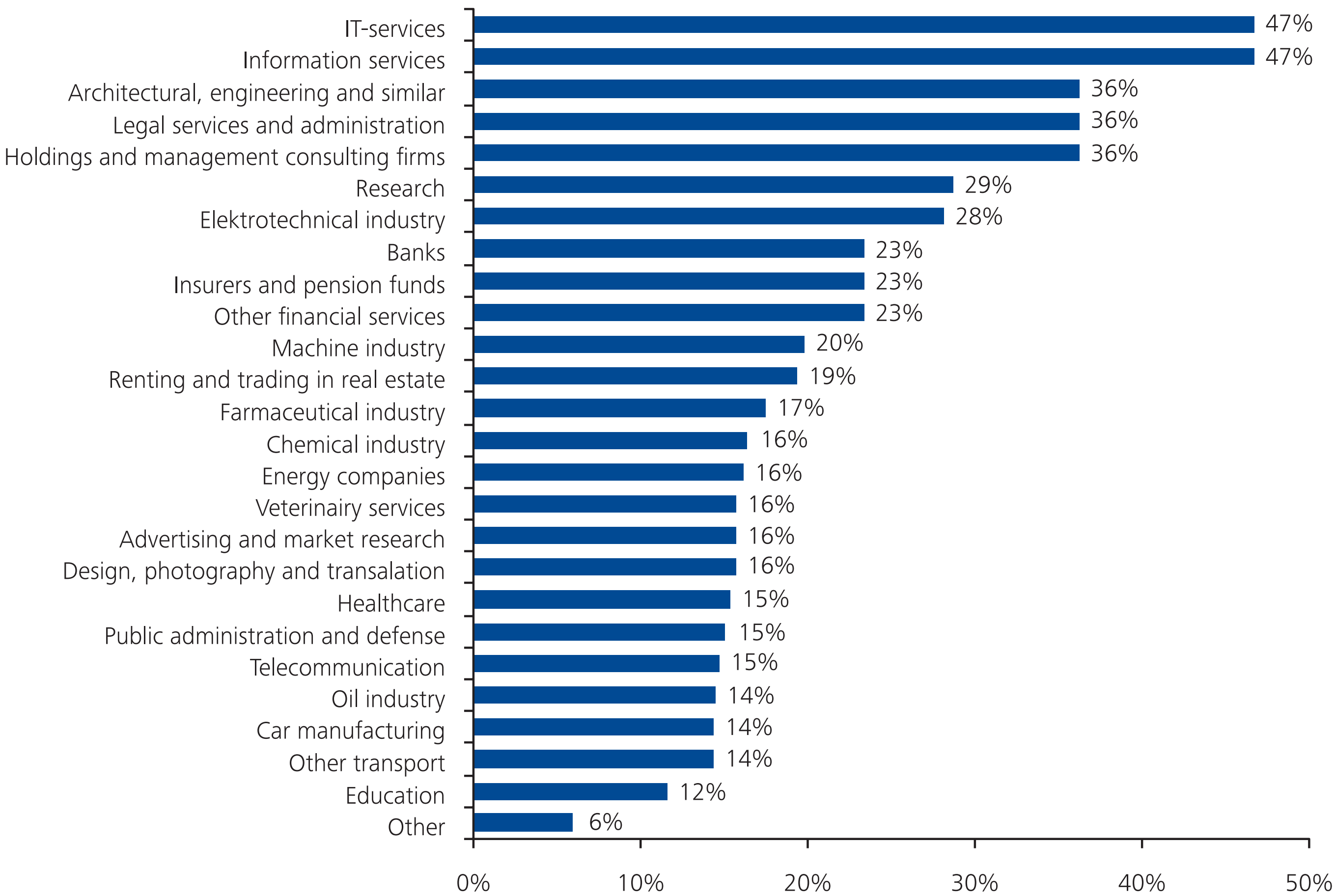
To identify how these jobs are distributed across industries, we used a matrix with CBS data that clusters the number of employees per occupation into 39 industry groups, according to the Standard Industry Classification (SIC). This results in the mathematical sciences intensity per industry.

The CBS input-output table (which we will use in the next chapter to assess the economic impact of the 0.9 million mathematical sciences jobs) uses more than the 39 industry groups the CBS uses to measure occupations. Where an exact match was not possible, we looked at which of the 39 industries was most similar. For example, we know that the construction industry has a math intensity of 7% and therefore assumed that the sub-industries 'road construction', 'general construction' and 'specialized construction' all have the same intensity - 7%. Appendix B includes the industry classification conversion table.

Looking across industries we can see that the math intensity by industry varies from 0% to 47% (figure 2). The top industries are Information services (software coding and maintenance, 47%), IT services (data storage, webhosting and hardware services, also 47%), Architects and engineering companies (36%), Holdings and management consulting firms (36%), Administration, audit, tax and legal services (36%) and Research (29%). These are all industries where employees work with calculations, formulas and algorithms every day.

In absolute terms the largest employers of mathematical sciences practitioners are Health care (82,000), Public administration and defense (72,000), IT services (71,000) and Holdings and management consulting firms (61,000). These industries benefit from their sheer size, in addition to a fair amount of usage of mathematical sciences.

Figure 2. Top 25 industries by mathematical intensity



Source: CBS, Deloitte Analysis

3. Mathematics supports a quarter of Dutch national income

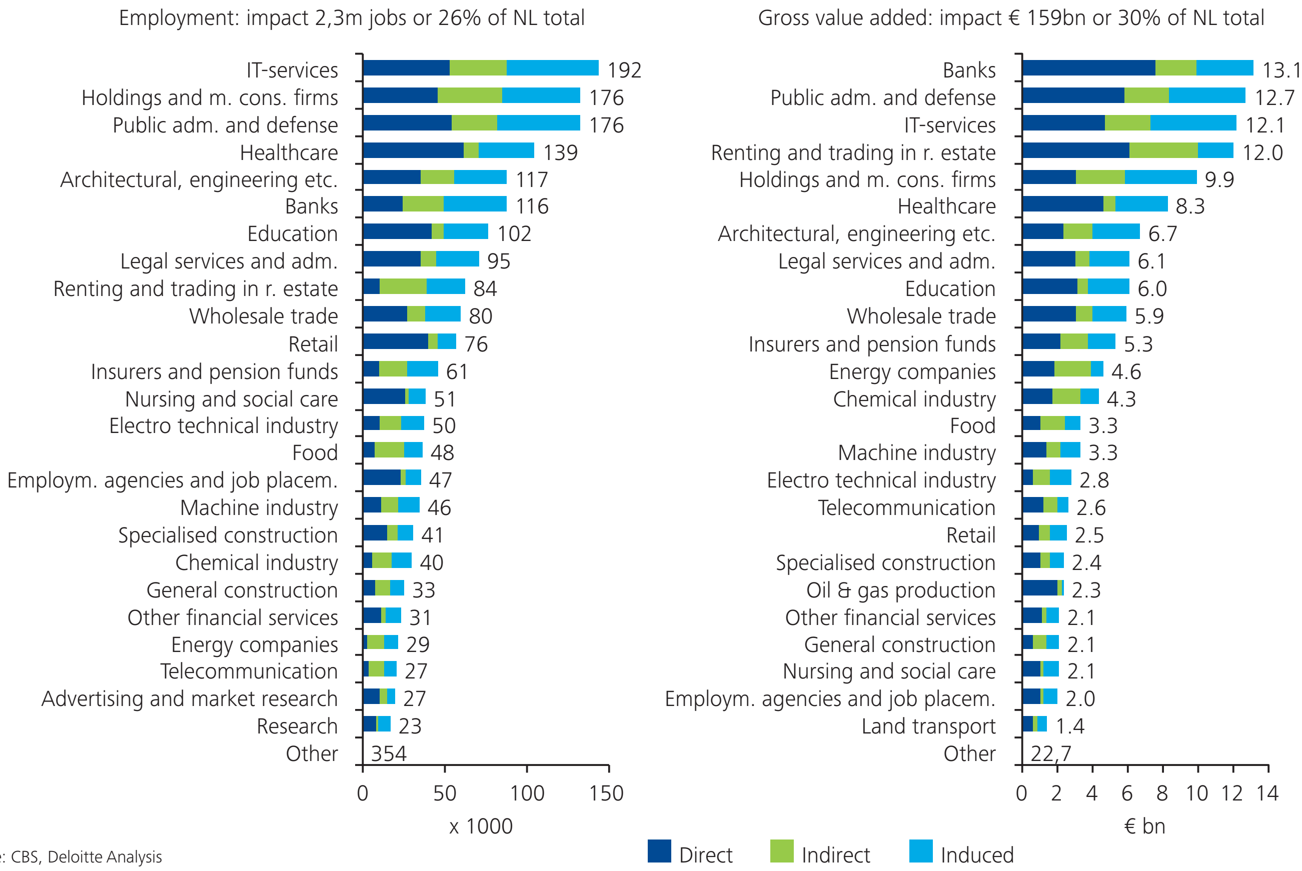
The 900,000 mathematical sciences jobs contribute to the Dutch economy in three ways:

- First, these jobs create income for the people who work in those jobs. This is called the *direct* effect.
- Second, the industries where these people work, procure goods and services from other industries which in turn procure from other industries as well, and so on. The impact of these purchases is called the *indirect* effect.
- Finally, the impact of the household spending resulting from direct and indirect effects of mathematical sciences jobs. This is called the *induced* effect.

These effects can be calculated with an input-output (IO) table of the Dutch economy. The concept of the IO table has been developed by Russian economist and Nobel Prize winner Wassily Leontief. He used this method to determine the effects of changes in one industry on other industries in the economy. The core of the method is a table with data on supply and use of products and services by industry. Additional information by industry, e.g., salaries, taxes and import and export data, are also included. Constructing an input output model involves a complex process. Broadly speaking, the IO table is used to give a matrix of coefficients, detailing the proportion of inputs sourced by an industry for all other industries, and for labor. The coefficient matrix is then subtracted from the identity matrix before being inverted to give the Leontief inverse. This matrix then details output multipliers. A multiplier is a factor that can be applied on a change in industry volume to obtain the total effect in the economy. These multipliers can be converted to employment and gross value added multipliers. Appendix D includes a more detailed description of the input-output technique.

Based on these data and the number of mathematical sciences jobs, we can infer that the direct impact of mathematical employment on the Dutch economy is about € 71bn in Gross Value Added (GVA), this is 9.5% of the national total. The GVA per job is € 77,000, 21% above the national average. GVA is a standard measure of the value of goods and services produced in an area of an economy. Total GVA equals Gross Domestic Product (GDP) minus intermediate production.

Figure 3. Impact of the mathematical sciences on employment and gross value added



Source: CBS, Deloitte Analysis

The industries with the highest direct contribution are Banking (€ 7.6bn), Renting and trading in real estate (€ 6.1bn), Public administration and defense (€ 5.9bn), IT Services (€ 4.7bn) and Healthcare (€ 4.6bn). This is a direct consequence of the high number of mathematical sciences jobs and the relatively high salaries in these industries.

The indirect effect amounts to € 37bn in GVA, 6.9% of national GVA or 540,000 jobs (€ 68,000 per job). This is calculated using the previously discussed multipliers. The direct effect is subtracted to show only the additional indirect effects. The industries with the highest indirect impacts are Renting and trading in real estate (€ 3.9bn), Holdings and management consulting firms (€ 2.8bn), IT Services (€ 2.6bn), Public administration and defense (€ 2.6bn) and Banks (€ 2.3bn). This can be explained by the fact that the top direct industries spend a lot of money on real estate, the government, consulting, and information technology

"Mathematical sciences support 26% of all jobs in the Netherlands and contribute to 30% of Gross Value Added"

The induced effects generate another € 51bn in GVA (13.2% of the national total) due to consumer spendings. This means 790,000 jobs, at € 65,000 per job. These numbers refer only to the additional effects above and beyond the direct and indirect effects. The industries with the largest induced impact are IT Services (€ 4.9bn), Public administration and defense (€ 4.3bn), Holdings and management consulting firms (€ 4.0bn), Banks (€ 3.2bn) and Healthcare (€ 2.9bn).

This means that mathematical sciences generate a total of over 2¼ million jobs and almost € 160bn of GVA. This translates into 26% of all jobs and 30% of Dutch GVA (Figure 3, Appendix C).

Table 1. Comparison of The Netherlands and the United Kingdom

	Employment (x1000)				Gross Value Added (€ / £)			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
NL	928	542	789	**2,259**	€ 71bn	€ 37bn	€ 51bn	**€ 159bn**
	10.7%	6.2%	9.1%	**26%**	13.2%	6.9%	9.5%	**30%**
UK	2,800	2,900	4,100	**9,800**	£ 192bn	£ 155bn	£ 208bn	**£ 555bn**
	9.8%	10.2%	14.4%	**34%**	16%	12%	15%	**43%**

Though these numbers are very substantial, they are still lower than what we have found for the UK economy. The direct employment effects were simlar, but because mathematical sciences jobs in the UK are located in larger industries and are generally better paid as well, they result in a higher share of GVA and larger indirect and induced effects. The UK economy is influenced more by banking and high tech than the Dutch economy. The UK is also less egalitarian than the Netherlands, which benefits the higher income jobs that are typically associated with mathematical sciences.

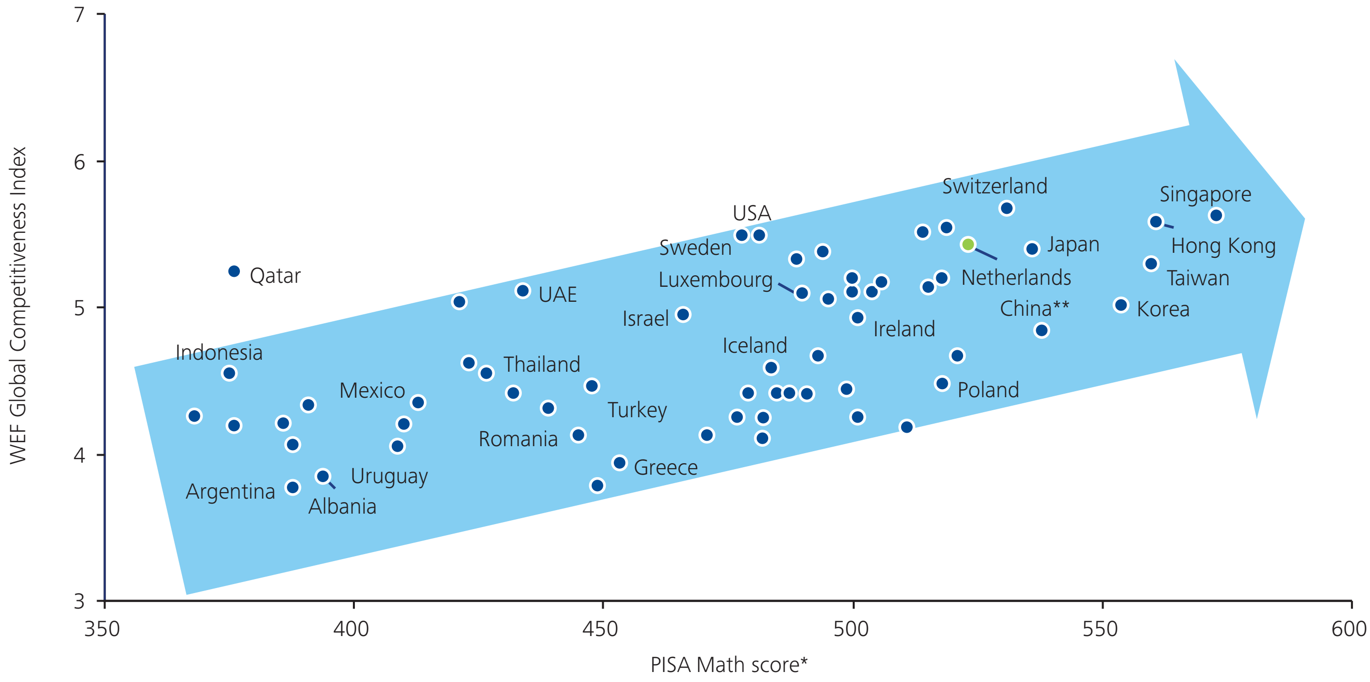
4. Mathematical sciences are a key pillar of an advanced economy

Our economic impact assessment clearly demonstrates that with 26% of employment and 30% of gross value added, mathematical sciences are a key contributor to the Dutch economy. But more fundamentally, a strong foundation in mathematics is critical for the success of any advanced, innovative economy.

Figure 4 shows the relation between the mathematical abilities of pupils per country, as measured by the OECD in its PISA study, and the Global Competitiveness Index for that country as defined by the World Economic Forum. The most competitive nations generally have populations with strong mathematical skills. For example, the Netherlands ranks 8th on the World Economic Forum list of most competitive nations for 2013 and also takes the number eight spot on the global list of mathematical ability of high school students.

Three types of economies
The World Economic Forum describes three types of countries: *factor-driven economies* which compete on low-skilled labour and natural resources (like Angola), *efficiency-driven economies* which rely on good education and well-functioning markets (think of Bulgaria) and *innovative economies* where businesses must compete with new products, technologies, processes and business models. These economies, including the Netherlands, require an exceptional level of sophistication to maintain their high standard of living.

Figure 4. Relation between mathematical ability and country competitiveness



* Mathematical ability as defined by OECD – PISA study among 15 year old

** PISA score of Macao

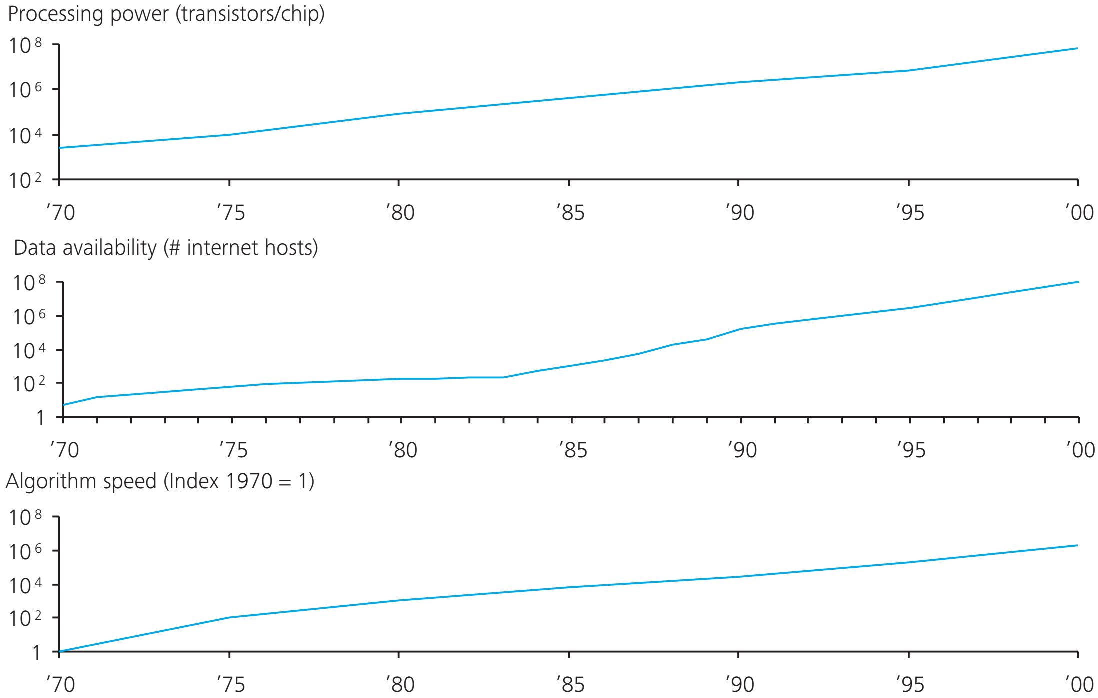
Source: World Economic Forum (2013), OECD-PISA (2013); Deloitte analysis

The revolutions in computational science, big data, statistics and analytics are likely to substantially increase the importance of mathematical sciences to society and a country's competitiveness in the coming decades. These revolutions are driven by three factors: more computing power, more data and better algorithms (figure 5).

Computing power has been growing exponentially for many years. Co founder of Intel, Gordon E. Moore, indicated in his 1965 paper that the number of transistors on a chip doubles every 18 months, resulting in exponential growth of computing power. His observation still holds true today.

> "Revolutions in computational science, big data, statistics and analytics are likely to substantially increase the importance of mathematical sciences"

Figure 5. Drivers of the big data, statistics and analytics revolution



Source: University of California, Intel, ESF, Deloitte Analysis

The rise of computing power is becoming even more relevant as more data is available to mathematical practitioners than ever before. The rapid rise of the internet as depicted by the number of internet hosts in figure 5 is an important driver. But more and cheaper measurement tools also add to this development. For instance, massive amounts of traffic data are gathered using video cameras, traffic counters and even cell phones in highway areas.

Finally, algorithms are getting smarter and faster. The increase in transistors on a chip is accompanied by a similar speedup achieved by mathematicians. The speed of these algorithms increases exponentially too.

Faster processors, more data and smarter algorithms allow not only more complex mathematical computations, they also enable faster and easier analyses for simpler problems. And the more people are trained to use these algorithms, the more productive an economy will be. Hence, a higher knowledge of mathematical sciences will likely be beneficial for an economy as a whole. The consequence is that a competitive economy needs to have a work force with sufficient training in the development and application of mathematical sciences.

5. Lack of fostering mathematical talent weakens Dutch competitiveness

The high ranking of the Netherlands on the World Economic Forum list of most competitive nations is based on evaluations of 114 criteria, ranging from institutional factors (e.g. judicial independence), to infrastructural factors (e.g. quality of roads), technological readiness (e.g. % internet users) and innovation factors (e.g. company spending on R&D).

Seven of these 114 criteria are linked to mathematics. The Netherlands is a top performer in some of these, but not in all. It underperforms in terms of the availability of scientists and engineers (globally ranked 41st), the quality of higher mathematics training (ranked 14th) and university industry collaboration in R&D (ranked 12th). Performance is above average in primary education enrolment and the quality of scientific research institutions (respectively 5th and 7th).

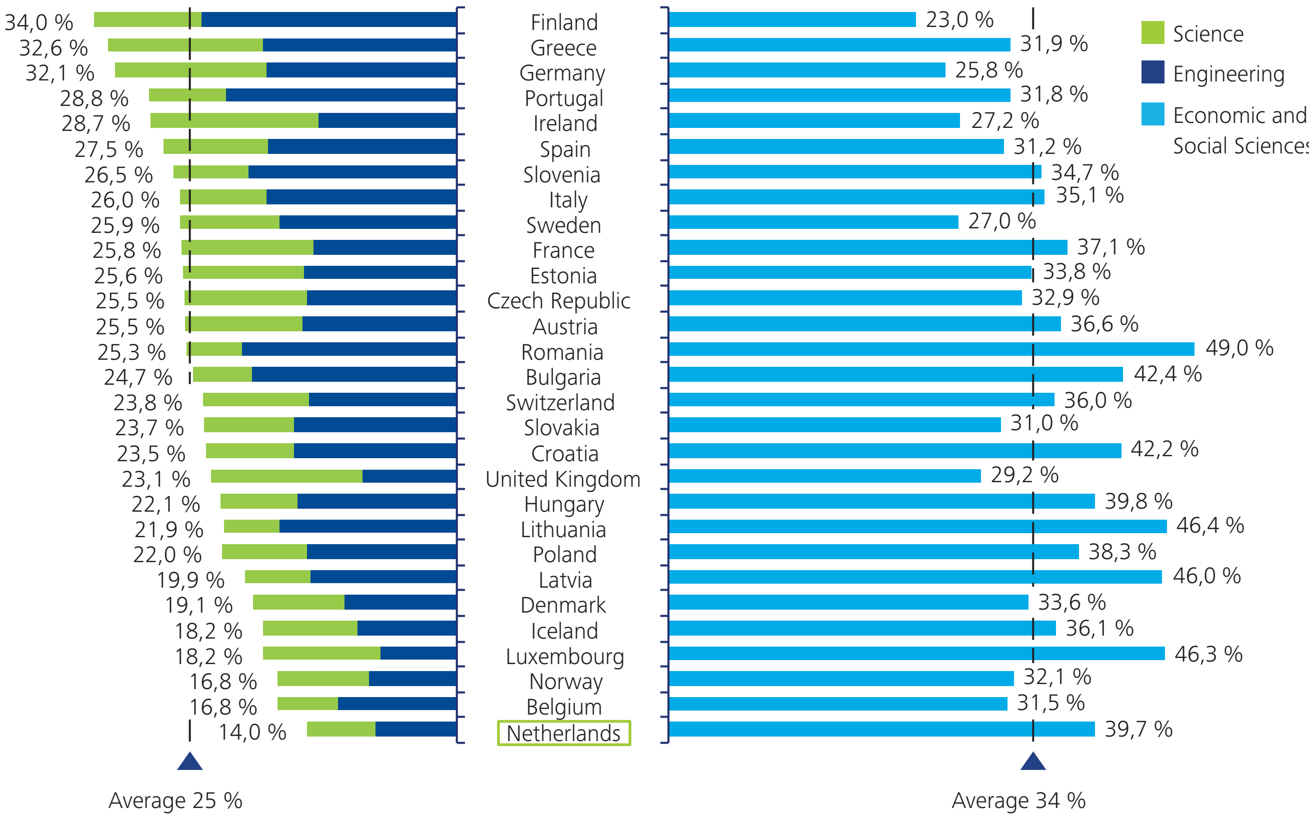
The shortage of scientists and engineers can be explained by declining higher education graduation figures. In 1970, 19% of graduates in higher education (research universities and universities for applied sciences or 'HBOs') studied science or engineering. This number grew to 22% in 1987, but started declining since and reached a low of 14% in 2011. As a result, the Netherlands has the lowest percentage of engineering and science students in Europe (figure 6). The European average is 25%; no other country has a percentage as low as the Netherlands.

"The Netherlands has the lowest percentage of mathematics, engineering and science students in Europe"

The number of mathematics students has been declining as well, dropping to only 200 new students in 2006, representing only 11% of science and less than 1% of all matriculates. Although the number has bounced back to about 500 in 2011, the number of mathematics students is still very low.

In sharp contrast, the share of economics and social sciences students is very high: the Netherlands is among the leader with almost 40% of students. This position is occupied together with tiny Luxemburg, the Balkan countries Romania and Bulgaria and the Baltic countries Latvia and Lithuania, which all have relatively low per capita incomes. Although economics and social sciences students do use mathematics, they tend to choose occupations with a lower mathematical intensity and this dilutes the share of mathematical sciences in the economy.

Figure 6. Share of graduates in higher eduction by discipline (2011)



Source: Eurostat, Deloitte Analysis

The shift away from mathematically inclined employees means an ever more critical foundation of an advanced economy is being eliminated in the Netherlands. It also stands to lose out on the big data, statistics and analytics revolution - the biggest technological trends of this time and age. A highly competitive nation has much more potential to benefit from this global trend than countries like Greece and Portugal, which still graduate a large number of scientists and engineers but lack technological readiness and a culture of innovation of a country like the Netherlands.

This would be a missed opportunity. At € 77,000 in GVA, one mathematical sciences job alone generates 21% more value than the average job in the Netherlands. And even the 1.4 additional jobs that are created from indirect and induced effects still generate substantial wealth (€ 66,000 per job, 5% above the average).

If the Netherlands would only be able to increase the effect of mathematical sciences employment to the UK level, it would add 700,000 direct, indirect and induced jobs. This translates into 8% more employment and a 9% larger economy.

Conversely, with only 14% of students graduating in science and engineering today, compared to a 17% share of all graduates in the workforce, the number of mathematical sciences jobs in the Netherlands could drop from 900,000 today to 740,000. With a proportional loss of indirect and induced jobs, this increases Dutch unemployment by 400,000 jobs, almost 5% of the total workforce. Added value in the Dutch economy would drop by € 30bn.

> "Better usage of mathematical sciences will enable the Netherlands to maintain its high standard of living"

Supporting a third of the Dutch economy, mathematical sciences are an important pillar of the Dutch economy today. And it can become even bigger if it is able to ride the wave toward big data, statistics and analytics, reinvigorating the Dutch economy in the process.

But this requires more mathematically trained people to enter the labour market. This obviously starts with educating more students in mathematics, science and engineering. There are first signs of recovery in these student numbers, but a more significant increase is necessary. Just as important is increasing the intensity of mathematical training in other fields, like economics, business and psychology. Mathematics university departments, though small and with few graduates, need to play a role as provider of fundamental mathematical know-how that ultimately flows into other parts of the university.

More and better usage of mathematical sciences will enable the Netherlands to retain its position as one of the most competitive countries in the world and maintain its high standard of living.

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- Centrum Wiskunde & Informatica

Appendices

A. Mathematical sciences percentage of occupational groups

Level	Occupation class	Occupation group	M%
Graduates from universities of Applied Science ('HBOs')	Teachers	Science and medical teachers	100.0%
		Engineering and agricultural teachers	100.0%
		Economics and legal teachers	10.0%
		Social and psychological teachers	10.0%
	Agricultural occupations	Agricultural occupations	33.6%
	Scientific occupations	Mathematical and science occupations	100.0%
	Engineers	Civil engineers	92.5%
		Road and water engineers	88.0%
		Metal engineers	100.0%
		Mechanical engineers	100.0%
		Electro technical engineers(automation)	100.0%
		Electro technical engineers(non-automation)	100.0%
		Process engineers	100.0%
		General technical occupations	75.0%
	Transport occupations	Transport occupations	41.3%
	Medical practitioners	General medical practitioners	20.0%
		Technical medical practitioners	55.0%
	Commercial and business occupations	General economic occupations	43.0%
		Business management occupations	76.3%
		Administration occupation(automation)	100.0%
		Administration occupation(non-automation)	81.0%
		Commercial occupations	37.3%
		technical procurers	86.4%
	Social occupations	Social occupations	16.9%
	Nursing occupations	Social sciences occupations	55.0%
		Nursing occupations	5.0%
	Manager	Managers	5.0%
	Other nec.	Other occupations nec.	5.0%
University graduates	Teachers	Science and medical teachers	100.0%
		Engineering and agricultural teachers	100.0%
		Economics and legal teachers	10.0%
	Agricultural occupations	Agricultural occupations	5.0%
	Scientific occupations	Mathematical and science occupations	100.0%
	Engineers	General engineering occupations	100.0%
		Road and water engineers	100.0%
		Electro technical engineers(automation)	100.0%
		Material and process engineers	100.0%
		Engineers nec.	100.0%
	Medical practitioners	General medical practitioners	60.0%
		Technical medical practitioners	67.3%
	Commercial and business occupations	General economical occupations	69.2%
		Business management occupations	70.0%
		Administration occupation(automation)	100.0%
		Administration occupation(non-automation)	84.2%
	Social occupations	Social occupations	6.7%
		Social sciences occupations	53.3%
	Manager	Managers	5.0%
	Other nec.	Other occupations nec.	5.0%

B. Industry classification conversion table

Industry group	Industry
Agriculture forestry and fishing	Agriculture
	Fishing
	Forestry
Mining and oil and gas	Mining
	Oil & gas production
Food and beverages	Beverages
	Food
	Tobacco
Textile and clothing	Textile and clothing
Wood and paper	Graphical
	Paper
	Wood
Oil industry	Oil industry
Chemical industry	Chemical industry
Pharmaceutical industry	Pharmaceutical industry
Rubber, plastic and non-metal products	construction materials
	Rubber and Plastics
Metal and metal products	Basic metals
	Metal products
Electro technical industry	Electro technical industry
Electrical devices	Electrical devices
Machine industry	Machine industry
Transport manufacturing	Car manufacturing
	Other transport
Furniture, machine and other manufacturing	Furniture
	Machine repair and installation
	Other manufacturing nec.
Energy companies	Energy companies
Water management	Waste and waste water management
	Water supply
Construction	General construction
	Road construction
	Specialized construction
Wholesale and retail	Car dealing and repair
	Repair of consumer goods
	Retail
	Wholesale trade
Transport and related services	Air transport
	distribution services
	land transport
	Postal and courier
	Water transport
Publishing and media	Film, radio and TV
	Publishing
Telecommunication	Telecommunication

Industry group	Industry
IT and information services	Information services
	IT-services
Hotels, restaurants and pubs	Hotel service
	Restaurants pubs and catering
Financial services	Banks
	Insurers and pension funds
	Other financial services
Renting and trading in real estate	Renting and trading in real estate
Professional services	Architectural, engineering and similar
	Holdings and management consulting firms
	Legal services and administration
Research	Research
Advertising, market research, design and veterinary services	Advertising and market research
	Design, photography and translation
	Veterinary services
Business services	Cleaners, gardeners and similar
	Employment agencies and job placement
	Other business services
	Renting of movable property

C. Math Intensity and direct indirect and induced employment and gross value added per industry

Industry	Math intensity (%)	Direct empl. (×1000)	Indirect empl. (×1000)	Induced empl. (×1000)	Direct GVA (€ m)	Indirect GVA (€ m)	Induced GVA (€ m)
IT-services	47%	71	45	75	4,682	2,599	4,856
Information services	47%	6	3	6	316	177	363
Legal services and administration	36%	47	13	35	3,048	813	2,254
Architectural, engineering and similar	36%	47	28	42	2,357	1,601	2,732
Holdings and management consulting firms	36%	61	52	63	3,029	2,834	4,063
Research	29%	11	2	10	570	121	664
Electro technical industry	28%	13	18	19	639	924	1,241
Banks	23%	32	34	50	7,576	2,338	3,223
Other financial services	23%	14	5	11	1,114	273	740
Insurers and pension funds	23%	14	22	24	2,150	1,622	1,568
Machine industry	20%	15	13	18	1,381	772	1,156
Renting and trading in real estate	19%	14	39	31	6,101	3,924	1,995
Pharmaceutical industry	17%	2	4	4	234	226	236
Chemical industry	16%	8	16	16	1,705	1,625	1,019
Energy companies	16%	4	13	11	1,791	2,086	725
Veterinary services	16%	1	0	0	100	4	25
Design, photography and translation	16%	5	4	4	354	238	247
Advertising and market research	16%	13	7	6	335	392	400
Healthcare	15%	82	12	45	4,649	692	2,931
Public administration and defense	15%	72	37	67	5,869	2,517	4,309
Telecommunication	15%	5	13	10	1,215	764	615
Oil industry	14%	1	3	3	457	435	173
Other transport	14%	3	3	4	165	167	228
Car manufacturing	14%	3	3	4	265	199	227
Education	12%	55	10	36	3,141	564	2,343
Mining	10%	0	0	0	57	21	16
Oil & gas production	10%	1	2	2	2,040	196	110
Electrical devices	9%	1	1	1	82	57	90
construction materials	9%	2	2	3	197	151	163
Rubber and Plastics	9%	3	2	3	183	130	181
Food	9%	11	24	14	1,030	1,373	919
Beverages	9%	1	1	1	141	83	79
Tobacco	9%	0	1	0	160	33	31
Publishing	7%	3	2	3	253	122	174
Film, radio and TV	7%	2	3	2	154	155	131
Specialized construction	7%	20	9	13	1,031	509	835
Road construction	7%	5	6	6	331	371	394
General construction	7%	10	13	11	581	792	697
Metal products	7%	6	5	6	438	338	410
Basic metals	7%	1	2	2	71	127	123
Security and private investigation	7%	4	0	1	84	18	81
Other business services	7%	3	1	2	107	82	104
travel agencies and travel services	7%	2	3	2	151	141	123
Cleaners, gardeners and similar	7%	11	2	4	297	95	253

Industry	Math intensity (%)	Direct empl. (×1000)	Indirect empl. (×1000)	Induced empl. (×1000)	Direct GVA (€ m)	Indirect GVA (€ m)	Induced GVA (€ m)
Renting of movable property	7%	2	3	2	327	174	154
Employment agencies and job placement	7%	31	3	13	1,024	152	813
Car dealing and repair	7%	10	4	6	522	232	384
Retail	7%	54	7	15	994	529	978
Repair of consumer goods	7%	1	0	0	32	13	19
Wholesale trade	7%	35	16	29	3,033	1,000	1,850
Furniture	7%	2	1	1	80	44	63
Machine repair and installation	7%	2	2	2	198	112	152
Other manufacturing nec.	7%	9	1	4	285	66	235
Waste and waste water management	6%	2	4	3	234	257	203
Water supply	6%	0	0	1	49	27	34
Goods and services nec.	6%	0	0	0	0	0	0
Non-profit associations, interest groups and hobby clubs	6%	5	1	3	223	83	193
Other personal service	6%	6	1	1	145	48	79
Postal and courier	6%	4	1	2	150	38	98
Air transport	6%	2	2	2	25	135	155
distribution services	6%	4	3	5	469	194	295
land transport	6%	11	4	7	645	252	477
Water transport	6%	1	1	1	77	61	72
Sports and recreation	5%	4	1	1	80	66	83
Arts and culture	5%	4	2	2	180	127	152
Textile and clothing	5%	1	1	1	57	33	41
Nursing and social care	4%	34	3	13	1,053	182	835
Wood	4%	1	0	0	35	18	25
Paper	4%	1	1	1	48	48	53
Graphical	4%	1	1	1	65	41	57
Forestry	2%	0	0	0	1	1	2
Agriculture	2%	5	3	2	199	193	119
Fishing	2%	0	0	0	3	2	2
Household employment	2%	6	0	0	53	0	1
Hotel service	1%	1	0	0	34	16	22
Restaurants pubs and catering	1%	3	0	1	71	28	48
Total	**11%**	**928**	**542**	**789**	**71,023**	**36,872**	**50,941**

D. Input-output analysis

The input output matrix

The input-output table depicts inter-industry relationships within an economy in a square matrix. This shows the dependency of each sector on the other sectors from supply and demand perspective. The input output matrix is expanded with additional items to find the gross domestic product. These items include subsidies, salaries, profits, imports, exports and expenditure and inventory changes. Figure 7 illustrates the concepts in a graphical and insightful way.

The input-output matrix in the Netherlands is published yearly by the Dutch statistics office. In this table, the economy is divided into 76 industries. A simplified version of this table is shown on the next page. The 76 industries are aggregated into just five:

- Agriculture, fishing, forestry
- Manufacturing
- Services
- Education and healthcare
- Other industries

The model

The input–output analysis is a linear model suited to calculate changes in an industry for supply and demand in the other industries. The key notion is that the growth in a sector increases purchases from other sectors, causing additional growth. This growth in its turn again causes additional growth. This process is not infinite, but gradually decreases until it phases out. A main use of input output analysis is to measure the economic impacts of events and (public) investments. It is also used to identify "key" or "focus" industries

Variables

A: Input-output matrix: the rows represent the supply of goods and services by industries, while the columns represent the use. The columns are normalized by dividing the values by the total production

t: Vector containing the total production per industry

y: Vector containing the total supply per industry

I: Identity matrix

Formulas

Intermediate supply ($\mathbf{A} \times \mathbf{t}$) plus final supply ($\mathbf{y}$) results in the total production ($\mathbf{t}$)

$$\mathbf{A} \times \mathbf{t} + \mathbf{y} = \mathbf{t}$$

This can be converted to:

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})\,\mathbf{t}$$

$$(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y} = \mathbf{t}$$

$(\mathbf{I} - \mathbf{A})^{-1}$ Is called the Leontief inverse. It can also be written as an infinite sum. Conceptually this can be seen as the consecutive steps in the economy:

$$(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots$$

Multipliers

The summation of the cells in one column of the Leontief inverse yields the output multipliers per industry. These can be multiplied by the output of that industry to result in the indirect or induced output:

- The indirect multiplier can be calculated using only the intermediate supply and demand of the industries
- The induced multiplier is calculated using the intermediate supply and demand together with the salaries and household spending

Determining the employment multiplier requires an extra step. The employment per industry is normalized by dividing by the total output to result in a vector with direct employment coefficients. Multiplying this vector by the Leontief inverse yields the indirect employment coefficients. The direct-indirect employment coefficient ratio is the employment multiplier. This operation is similar for the gross value added and other multipliers numbers in € m

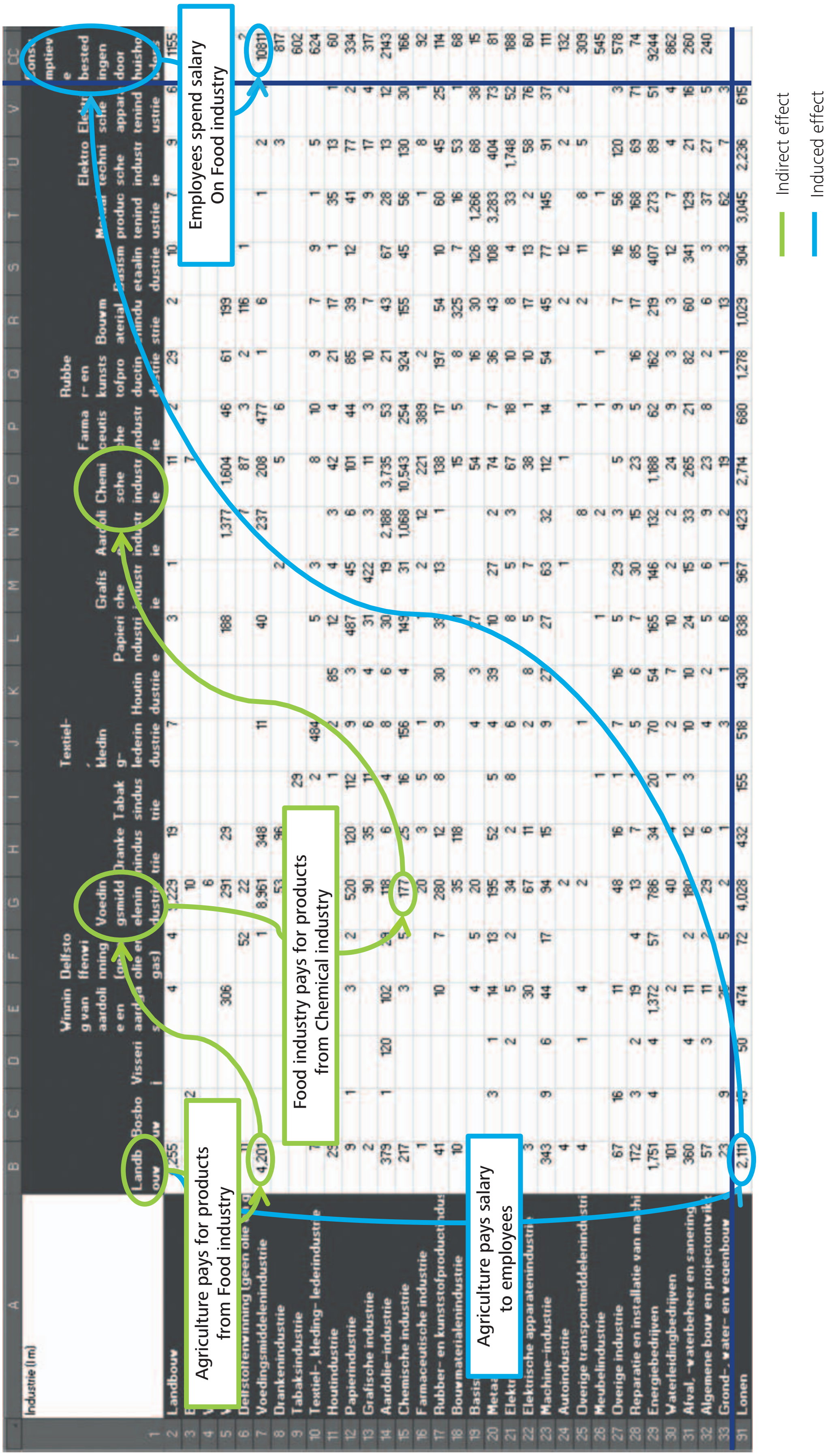
Intermediate usage matrix is used for input output analysis

	Agriculture, fishing, forestry	Manufac-turing	Services	Education and healthcare	Other industries	Intermediate supply	Export	Household spendings	Other consumption expenditure	Change of inventory	Non industry spending	Total
Agriculture, fishing, forestry	4.257	9.828	221	92	476	14.874	11.179	1.198	917	25	13.319	28.193
Manufacturing	8.074	114.955	14.864	4.610	33.212	175.715	194.801	29.158	61.425	270	285.654	461.369
Services	1.983	29.300	65.900	5.925	42.493	145.601	37.404	73.142	17.594	0	128.140	273.741
Education and healthcare	19	1.035	982	2.281	1.755	6.072	1.724	10.071	93.253	0	105.048	111.120
Other industries	628	9.425	14.871	5.431	28.366	58.721	44.625	50.085	162.706	-77	257.339	316.060
Interm. use* (excl. margin)	**14.961**	**164.543**	**96.838**	**18.339**	**106.302**	**400.983**	**289.733**	**163.654**	**335.895**	**218**	**789.500**	**1.190.483**
Import	2.514	143.273	22.948	4.602	37.342	210.679	206.941	40.125	26.821	2.856	276.743	487.422
Product related costs&subs.	1.646	22.748	5.834	5.308	10.657	46.193	34.737	64.161	-91.135	0	7.763	53.956
Other product costs	**4.160**	**166.021**	**28.782**	**9.910**	**47.999**	**256.872**	**241.678**	**104.286**	**-64.314**	**2.856**	**284.506**	**541.378**
Interm. use* (market prices)	**19.121**	**330.564**	**125.620**	**28.249**	**154.301**	**657.855**	**531.411**	**267.940**	**271.581**	**3.074**	**1.074.006**	**1.731.861**
Non-product taxes	549	1.249	3.790	397	1.483	7.468	0	0	0	0	0	7.468
Non-product subsidies	-1.006	-1.003	-1.239	-1.532	-775	-5.555	0	0	0	0	0	-5.555
Salaries	2.206	47.642	60.004	49.522	79.648	239.022	0	0	0	0	0	239.022
Social contributions	724	13.699	17.775	14.826	23.144	70.168	0	0	0	0	0	70.168
Operating surplus	6.599	69.218	67.821	19.803	63.493	226.934	0	0	1.040	0	1.040	227.974
Gross value add	**9.072**	**130.805**	**148.151**	**83.016**	**166.993**	**538.037**	**0**	**0**	**1.040**	**0**	**1.040**	**539.077**
Total	28.193	461.369	273.771	111.265	321.294	1.195.892	531.411	267.940	272.621	3.074	1.075.046	2.270.938

* Intermediate use

Summation of intermediate use and GVA results in GDP

Figure7. Flow of money through input-output table



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