How to deal with China on technologies where Europe has an edge has become an important facet to strategic engagement. This is especially true of key enabling technologies where China has proclaimed in its Made In China 2025 and Strategic Emerging Industry plans that it wants to be more self-sufficient. But how big is the perceived knowledge gap really? Within three clusters of key enabling technologies – semiconductors, photonics and drug development – China is compared to the Netherlands using scientific publication, patent application and awarded funding proposal data. Each cluster is markedly different. Within semiconductors, the Netherlands has a mature industry that is far ahead of China. China tries to catch-up in R&D and science, but it is not very successful yet. In photonics, the Netherlands has a budding ecosystem with a lot of talent and knowledge, that is at the same time still vulnerable. Drug development sees a lot of academic research in both countries, and at the same time the largest gap in scientific impact.

Scientific Research

Two measures have been used to determine the level of scientific research in China and the Netherlands. The amounts of scientific publications with a Chinese affiliation, as a measure for quantity of research, and the citation score as a measure of scientific impact, a common proxy for quality of research. This yields different results for different technology clusters and sub-domains.

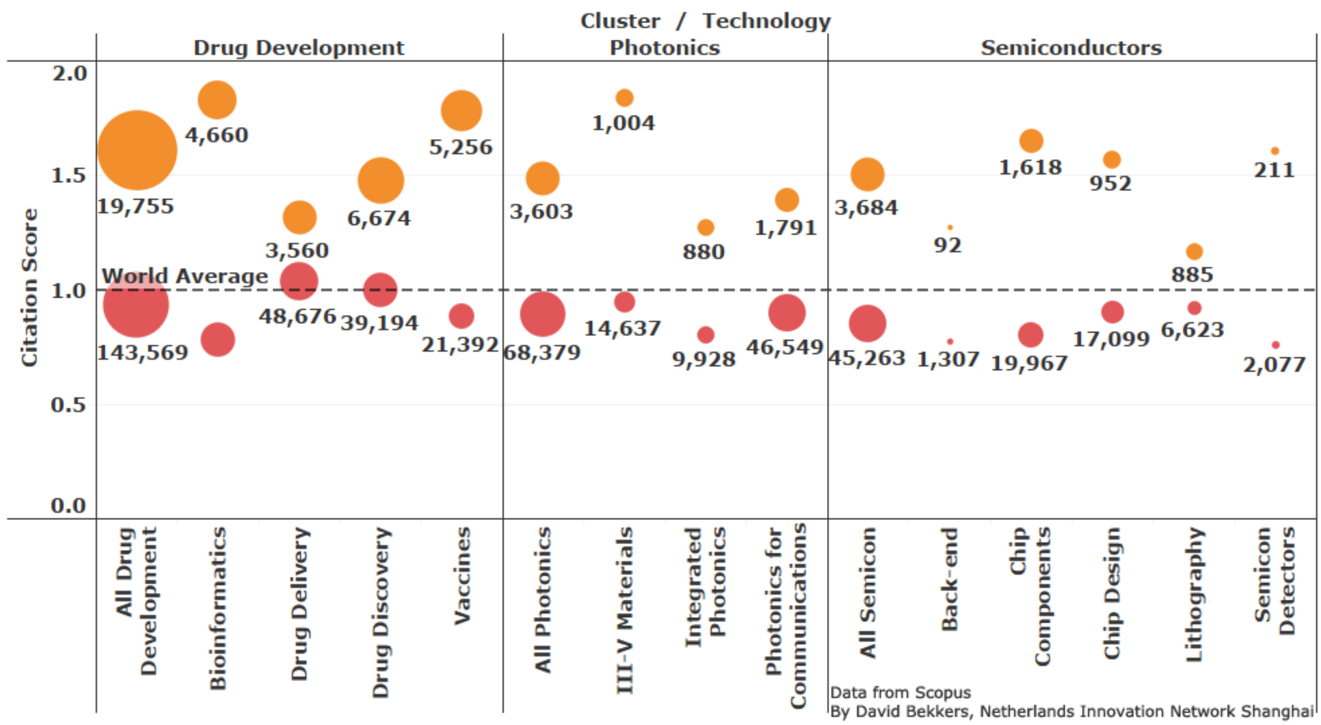

Figure 1: Quantity and impact of scientific publications from China (red) and the Netherlands (orange) per technology domain[1], 2013-2018. On the y-axis, the (field-weighted) citation score is used as a measure of research impact. A citation

[1] The technology domains have been identified using a set of keywords that occur in abstract, title or dedicated keywords lists, using expert opinion, complemented by a technique called 'pearl growing'. Consistency of keyword sets has been checked using cluster formation and the 'Leiden algorithm' on the basis of overlapping papers.

score of 1 means world average citations per article, with higher meaning more impact. A large vertical distance between the orange and red circles therefore indicates a large gap in scientific impact per paper. The size of the circles scales with the number of scientific publications, compared to the total national output to allow direct comparison between China and the Netherlands.

The knowledge gap between the Netherlands and China is still obvious in all the three technology clusters. China is still below world average in terms of scientific impact, while Dutch articles are more than 50% above world average. Obviously, China does produce many more publications, though some technologies receive more relative focus, such as photonics for communication, where China produced 25 times the number of articles the Netherlands produced. Conversely, vaccines were a more important scientific topic in the Netherlands (at least until 2018). While China on average produced 8 scientific publications for every Dutch publication, within vaccines it produced only 4 times as much.

Within some technologies the difference in scientific impact is relatively small. Drug delivery is one such case, the only field where China is already above world average. Interestingly, lithography is another, despite the near monopoly that Dutch company ASML has when it comes to lithography equipment for the semiconductor industry. At the same time this also provides a possible explanation. ASML is so intertwined with Dutch research on this terrain, that interesting research results will more likely find their way to a patent than a scientific publication. This hypothesis is supported by a large number of top patents from Dutch applicants in lithography.

The largest knowledge gaps exist in III-V materials (photonics), bioinformatics and vaccines. III-V materials is also recognized by PhotonDelta as one of the strengths of the Netherlands, and in particular the Eindhoven region. Vaccines have been a long-standing strength of the Netherlands.

It is important to note that China's citation scores in the photonics and semiconductor clusters are steadily improving, with 6% per year on average. If this trend continues, China will start nearing Dutch scientific impact per paper around 2025. However, for drug development, the gap has been more or less constant.

An important caveat is that these conclusions are all based on averages. Especially for larger fields of science, it is possible that world-class Chinese top universities are punching far above China's weight, masked by a mediocre performance in the rest of the country.

Patents

Patents can be used in a similar way as scientific publications to provide insights into the R&D position of companies in both countries. Patents are also cited, by examiners or other patent applicants. Next to citation scores, we also have access to the market coverage of a patent (the jurisdictions in which the patent offers protection). Combining these two leads to the 'patent power' as a measure of the average strength per patent.

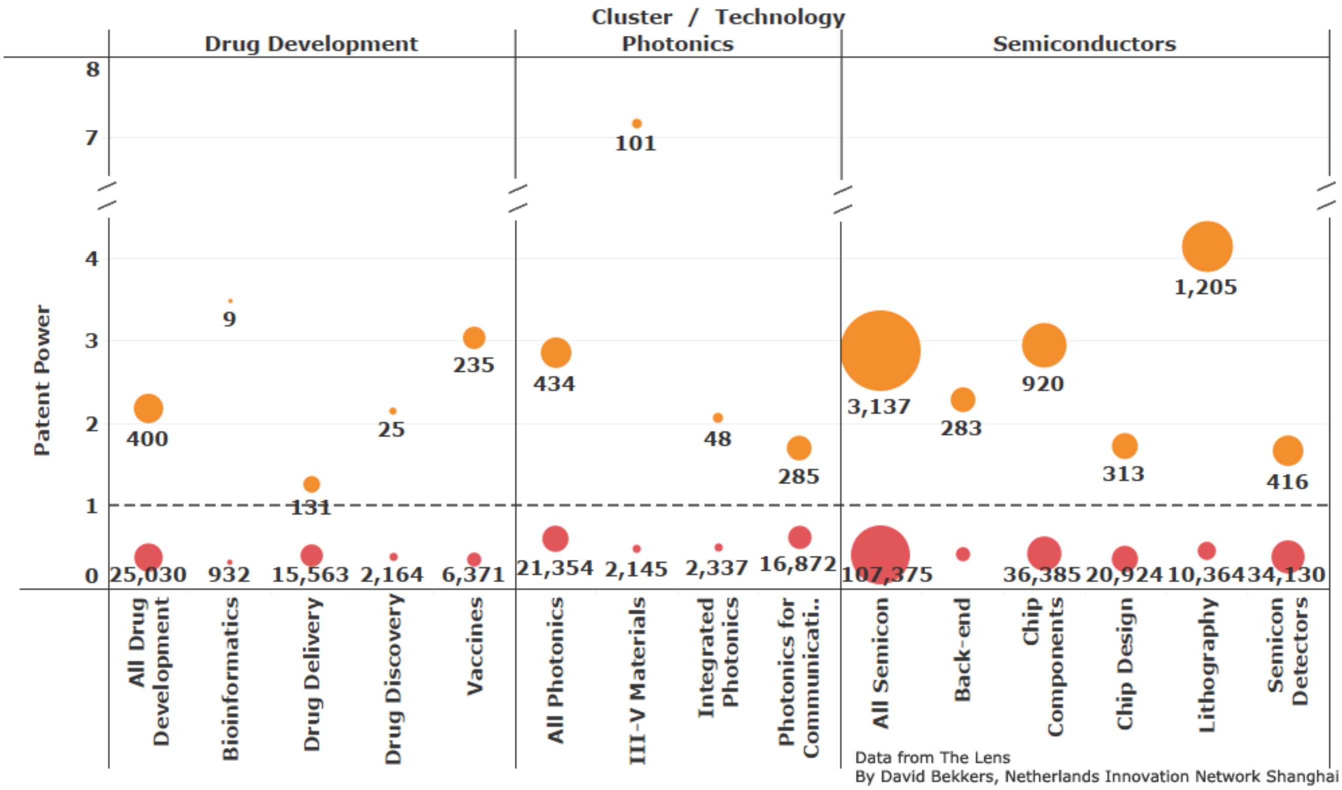

Figure 2: Quantity and strength4 of patents from Chinese (red) and Dutch (orange) applicants per technology domain, 2013-2018. On the y-axis, the patent power is used as a measure of research impact, the product of the citation score and the market coverage. A market coverage of 1.0 means the patent offers protection in a number of economies exactly equal to the GDP of the US. A large vertical distance between the orange and red circles therefore indicates a large gap in average strength per patent. The size of the circles scales with the number of new patent families with priority from 2013-2018, compared to the total national output to allow direct comparison between China and the Netherlands.

We can draw some similar conclusions for R&D as for research. The knowledge gap is again clearly visible, differing slightly per technology cluster, though clearly smaller for drug development. Again the large knowledge gap on III-V materials (photonics) is clearly visible. The difference in patent power for lithography is also striking. It is also the number one technology for the Netherlands when it comes to quantity of patent applications, while for China it comes in at the sixth position.

At least in a relative sense, the leading position of the Netherlands in lithography is clear. However, looking at absolute numbers, from 2013-2018 Chinese applicants still applied for nine times more lithography patents than Dutch applicants. To understand this, it is important to realize there are different types of lithography. At least 25% of lithography patents in China concern applications in display technology, a relative low-tech field. As for the two main cutting-edge technologies at ASML, EUV and high-NA, there are only two Chinese companies filing patents: Semiconductor Manufacturing International Corporation (SMIC), China's most advanced foundry (filing patents on applications of EUV, not on equipment). There is also Shanghai Microelectronics Equipment (SMEE), which already delivers lithography machines on (much) less advanced technology nodes. With only 6 patents in EUV/high-NA it is a dwarf compared to ASML.

In general, it is known that China had a 'patent bubble' in the period considered. With a policy of tax cuts for innovative companies, the Chinese government has caused large numbers of patent applications that are not always valuable. However, relative differences in patent amounts between technology domains are still considered valuable information, as are patent powers.

A similar problem exist for universities, that file much larger numbers of patents applications than Western universities, presumably often for evaluation purposes rather than commercial use. A large number of the Chinese lithography patents indeed comes from knowledge institutes, in line with the strong position in scientific publications. Active institutes are the Chinese Academy of Sciences (CAS) institutes such as the Changchun Institute of Optics & Fine Mechanics, the Institute of Semiconductors, and the Institute of Microelectronics. CAS has a clear focus on lithography, but does not generate a lot of impact, given the patent power of its patents.

The semiconductor industry is the most important in the dynamics between the Netherlands and China, given the amounts of patents[2]. More than half of the Dutch patent families come from ASML, NXP and ASM International. The gap is largest in front-end and manufacturing (components). In chip design and detectors it is smaller. This is in line with the conclusions of other analysts. Companies like Huawei have been successfully designing their own chips for years but are dependent on companies like TSMC and Samsung to actually produce their chips.

Photonics is a relatively young industry compared to semiconductors. Please note that in this article more established optoelectronics segments like lighting, industrial lasers and solar energy (photovoltaics) were not taken along in the photonics industry, which is common in the Netherlands, but not everywhere else. In photonics for communication, the knowledge gap is smallest. Again, a company like Huawei is leading the way, creating scale with applications within 5G and datacenters. It is the only technology domain in which Chinese applicants have applied for large numbers of international patents. Big Chinese companies with access to large-scale applications, and smart but small companies in the Netherlands on integrated photonics and III-V materials make for an interesting dynamic between the two countries. This has for example manifested itself in acquisition attempts by Chinese companies, such as towards Smart Photonics[3].

Drug development is mainly an academic affair in the Netherlands. In bioinformatics there are not even enough patents anyway to make solid conclusions about quality of R&D in the Netherlands. That doesn't mean there is no industrial activity, but at least that activity is not being expressed in patent applications by companies registered in the Netherlands. The world leading companies in this area are located outside both China and the Netherlands, for example in the US, Germany and Switzerland. However, it is known China is quickly trying to catch up. There is a lot of activity in development of innovative drugs, especially in the most recent few years and after COVID-19.

Vaccines are an exception in the Netherlands. Two companies are leading, Intervet BV and Janssen Pharmaceuticals. They both have a strong base in the Netherlands but are part of non-Dutch multinationals

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[2] This is clear not just from the amounts of patent applications. Both China and the Netherlands have a market share in the semiconductor industry that is twice as large as in drug development.

[3] See for example https://www.bloomberg.com/news/articles/2020-09-01/how-china-made-the-netherlands-question-its-free-market-beliefs

(Merck and Johnson & Johnson). Janssen is of course famous for the Janssen COVID vaccine. There are also a number of smaller, Dutch-owned business active in this segment.

Next to the considered technologies, there are a number of key enabling technologies of high relevance to drug development that were not taken along in this analysis. For example, the Netherlands has a lot of interesting technology in the field of lab-on-a-chip and organoid technology.

Science Funding

China's scientific output from 2013-2018 has already been shown. Central government science funding adds an extra dimension to this. Instead of output, we look at input – a clearer image of central government priorities as opposed to bottom-up priorities. On top of that, it is forward looking instead of backward looking.

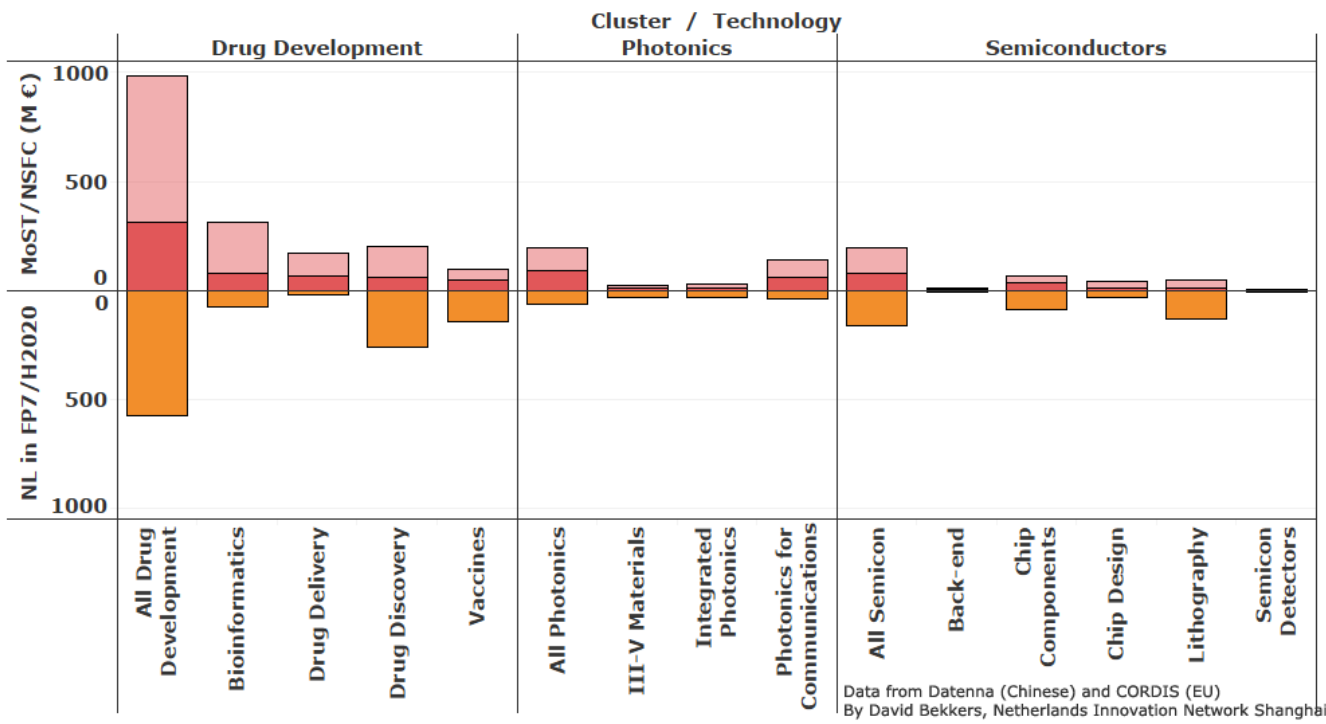

Figure 3: Awarded science funding per technology by China's most important national funders Ministry of Science and Technology (MoST) and Natural Science Foundation of China (NSFC), compared to funding awarded to projects with at least one Dutch partners in the European Commission's Framework Program 7 (FP7) and Horizon 2020 (H2020), 2015-2020. Amounts in millions of euros, real terms. MoST and NSFC publish limited data for a number of recently awarded funding proposals, which makes it hard to identify all of the awarded project proposals. The dark red part of the bar plot shows the minimum amount that is identified directly. The light red part is an estimated guess of the total awarded amount, based on how much data we know is missing.

Photonics has received relatively little central government funding compared to the amounts of publications 2013-2018. Almost all has gone to photonics for communications. Photonics is also barely used as a container in Chinese policy discourse, very different from the Netherlands, where it is considered one of the core clusters of key enabling technologies. At the same time drug development is overrepresented. Perhaps this means we will start to see more publications in drug developments in the coming years.

A few technologies are interesting to highlight. Firstly, lithography and drug discovery, because of the large amounts that Dutch researchers get awarded from FP7 and H2020, more than MoST and NSFC have spent in total. Within lithography Dutch organizations are involved in 60% of the total H2020 budget for the technology.

It is important to keep in mind, that like in Europe with its national funding agencies, China also has different funders that are not taken along in this data. For example provincial governments, but within lithography in particular CAS will also be a big funder.

On the Chinese side bioinformatics, drug delivery and photonics for communication are relative priorities that we can perhaps expect more scientific activity on in the coming years.

Conclusion

The three types of data present a snapshot of the dynamic between the Netherlands and Chinese within the three technology clusters. This report does not aim to address how to respond to these dynamics, but only to give an overview of the current situation and the knowledge gap between China and the Netherlands.

Within semiconductors, the Netherlands has a mature industry, with large companies such as ASML and NXP. On the Netherlands' strongest areas such as lithography and components the knowledge gap with China is still large and not closing any time soon. That does not mean China is not trying to catch up. This is clearly visible in academic research, for example at institutes of the Chinese Academy of Sciences. We can expect continued interest from China in the Dutch ecosystem. Chinese companies are stronger on detectors and chip design.

Photonics is a relatively young industry, where the Netherlands has a strong ecosystem, both in science and in R&D far ahead of China. China benefits from a large market and large scale, particularly in communication technology, also one of the first major envisioned application for integrated photonics and III-V materials. Therefore we can expect more interest from Chinese organization to invest in Dutch companies or set up partnerships. Because of scale-up possibilities in China this can be interesting proposals for individual companies. At the same time, the Dutch ecosystem can still be described as fragile.

The Netherlands has strong companies active in vaccine development. Apart from that, drug development is mainly an academic affair in the Netherlands. The largest pharmaceutical companies are located in third countries. However, it is known that in recent years the pharmaceutical industry is booming in China. This is not yet fully captured in the data, that mostly runs until 2018.

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