AN ECONOMIC IMPACT ASSESSMENT OF LERO

The Irish Software Research Centre using Input-Output Analysis

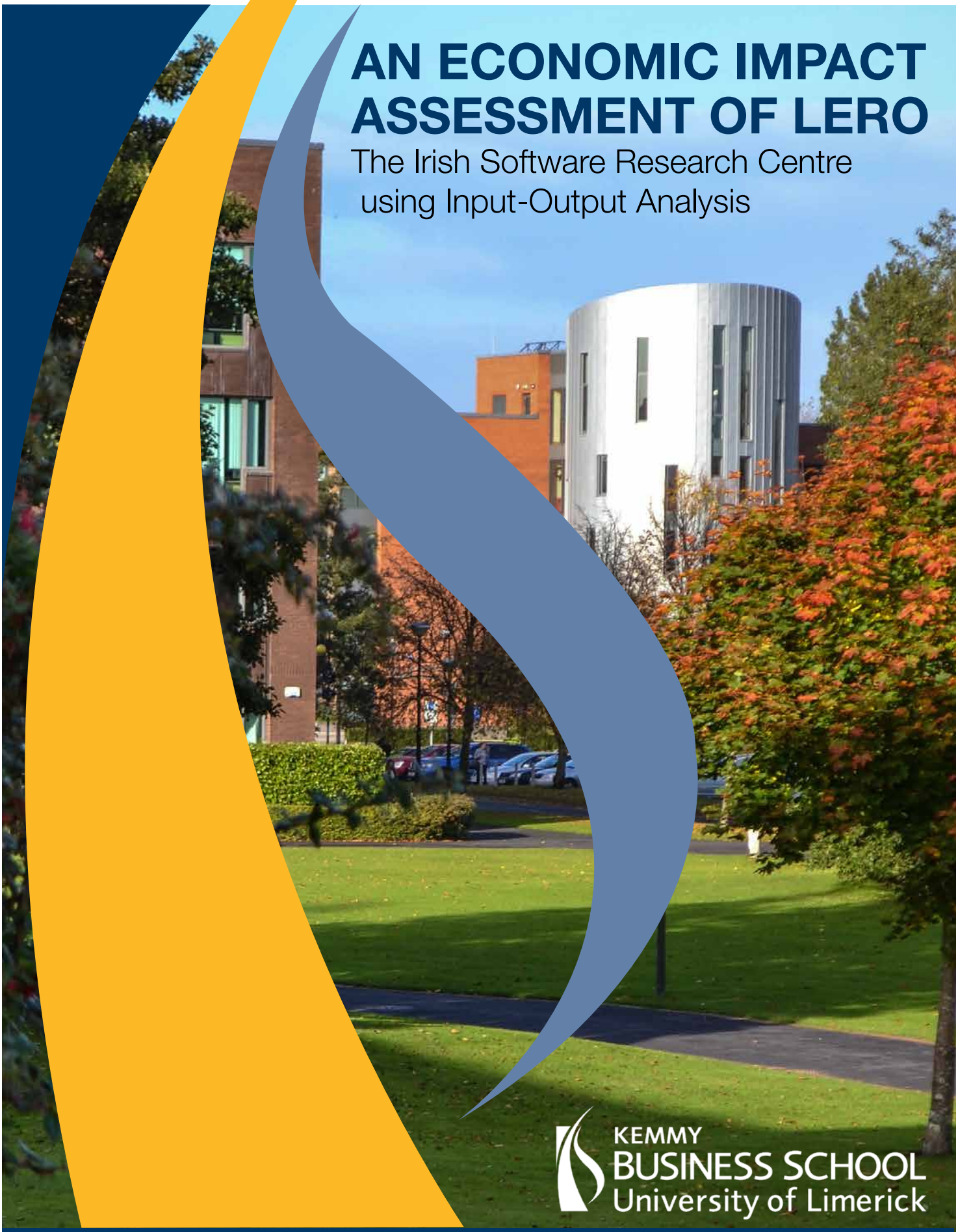

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Table of Contents

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Executive Summary

This report was commissioned by Lero (the Irish Software Research Centre), to investigate its economic impact on the Irish economy through its expenditure.

Lero is home to leading software research teams from seven Universities and two Institutes of Technology in Ireland. Lero is focused on pursuing excellent research, which is highly translational and has a strong industry focus.

Since 2005, Lero has received €94.42 million from national funding agencies including Science Foundation Ireland and internationally from the European Union (EU), as well as €4.27 million from industry. This report seeks to answer the following question: *For every €1 invested in Lero, does the Irish economy receive more than €1's worth of economic activity?*

To address the above question, the report applies an input-output analysis to 13 years of administrative data obtained from Lero (2005-2018). Input-output analysis is a well-established method of assessing the economic contribution of individual institutions, such as Lero, to the national economy through expenditure.

The findings demonstrate that for the period **2005-2018**, **every €1 invested in Lero by public funding agencies and industry partners contributed €5.25 to the Irish economy on average.** For the same period, Lero has contributed **€515.32 million** to gross output nationally. In addition, Lero's economic activity has contributed to the creation of **2,678** jobs nationally. **For every person working in Lero, 1.5 jobs are generated nationally** (this includes direct employment attributable to Lero and induced employment in the wider economy).

In summary, the input-output analysis undertaken in this report demonstrates a significant contribution by Lero to the Irish economy. The results of this analysis highlight the benefits to Lero and the wider economy of investment in publicly funded research by funding agencies in Ireland and the EU.

An Economic Impact Assessment of Lero-the Irish Software Research Centre, using Input-Output Analysis

Section 1: Introduction to Lero and its activities

This report was specifically commissioned by Lero to assess the economic impact of Lero on the Irish economy using input-output analysis. The approach adopted is based on recent economic impact assessments of Irish Higher Education Institutions by Zhang et al. (2017) and two Irish research centres by CRANN/AMBER (2016).

Founded in 2005, Lero is Ireland's national software research centre, funded primarily through Science foundation Ireland (SFI). Headquartered at the University of Limerick, Lero is home to more than 200 researchers across all seven Irish Universities and two Institutes of Technology. Lero's overall vision is to establish Ireland as a location synonymous with high quality software development, to the extent that 'Irish software' can enter the lexicon in the same way as 'German automotive' or 'Scandinavian design'. Lero's goal is to represent a 'one-stop shop' single point of contact for industry and national agencies (e.g., Industrial Development Agency (IDA), Health Research Board (HRB), various city and county councils) to access a nationwide network of leading software researchers and their teams. This ensures the involvement of industry in helping define and benefit from Lero's research agenda — the latter clearly evidenced by the fact that since 2015, Lero's industry partners have committed almost €5 million in 80 collaborative research projects[1]. In 2018, Lero was awarded the Institute of Electrical and Electronics Engineers (IEEE) Computer Society Technical Council on Software Engineering (TCSE) Synergy award. The IEEE TCSE Synergy award is a competitive international award which recognises research centres for outstanding industry collaboration[2].

Since its inception in 2005, Lero researchers have published over 2,000 peer-reviewed academic papers, with many of Lero's researchers publishing in the leading journals in their fields. Lero researchers are among the top in their disciplines with more than 100 thousand citations to their research. A recent bibliometric analysis[3] of Lero's research performance found that Lero research performs well in comparison to similar research centres internationally. The bibliometric analysis revealed that Lero research is cited 96% more times than the expected norm for the field; 31% of Lero research is published in the Top 10 percentile of most cited journals in the field; and 21% of Lero research is in the Top 10 percentile of most-cited papers in the field.

As demonstrated above, Lero has a defined vision for research excellence and impact, as well as a strong record of academic research performance and engagement with industry. However, the sole focus of this report is on assessing the economic contribution of Lero to the Irish economy using input-output analysis.

Input-output analysis captures the overall effect of spending by institutions such as Lero on the national economy. As highlighted by Hermannsson et al. (2013, p. 714), input-output analysis

[1] Information garnered during discussions with Lero's Director.
[2] See http://www.cs-tcse.org/2018-call-for-nominations
[3] This analysis was performed internally by Lero in May 2017, using the SciVal tool on the Scopus publications database.

facilitates this assessment by calculating the "multiplier, or 'knock-on', impacts of any expenditure injection, obtained by summing the subsequent internal demand feedbacks within the economy". While input-output analysis is a well-established economic impact assessment method, it must be acknowledged from the outset that it deals exclusively with expenditure impacts. Expenditure impacts are only part of a bigger picture concerning the economic and social impacts associated with institutions such as Lero (e.g., the knowledge produced and human capital fostered in research and development (R&D) activities). While desirable, a more holistic form of economic impact assessment is beyond the scope of this report (see e.g., Lenihan 2011). In line with Zhang et al. (2017) and CRANN/AMBER (2016), this report focuses exclusively on the economic impact derived from Lero's expenditure.

The remainder of the report is organised as follows. Section 2 outlines the objectives of the report. Section 3 details the methodology of input-output analysis and the calculation of output multipliers. Section 4 describes the data used in the subsequent analysis. Section 5 presents the results of the input-output analysis, while Section 6 offers some interpretation of these results. Section 7 concludes.

Section 2: Objectives

Education and research are vital for national competitiveness and for wider economic prosperity (Krammer 2017). Public funding for education and research is often justified on the basis that these activities have positive externalities for both the economy and society (Mazzucato and Semieniuk 2017).

In the 13 years between 2005 and 2018, Lero received €94.42 million in public funding from the Irish Government through funding agencies such as Science Foundation Ireland (SFI) and internationally from the European Union (EU), as well as €4.27 million from industry. As a result of this funding, Lero has been recognised for making significant scientific contributions in the field of software research, as evidenced by the bibliometric analysis mentioned earlier. In addition, Lero has been particularly successful at leveraging academic quality to forge strong linkages with industry partners. This aspect of Lero's research agenda is in the spirit of translational research, where excellent research translates into real impacts for the economy and society more broadly.

While evidence suggests that Lero is clearly effective at performing its primary functions (i.e. scientific research and industry engagement), SFI's strategic policy document *Agenda 2020* makes clear that publicly funded scientific research should have broader (i.e. beyond academia) impacts on the Irish economy (SFI 2012). This report contributes in this regard by assessing the economic impact of Lero on the Irish economy using input-output analysis as detailed below.

Lero produces many outputs that are used by other sectors of the Irish economy. For example, Lero's research on adaptive security has been implemented in a major product by a US multinational company based in Ireland, and a number of patents have been filed for this research. In addition, Lero's research on global software development processes has been licensed to an Irish Small and Medium-Sized Enterprise (SME) to be used in its consultancy and training operations[4]. Outputs from Lero such as these are important for fostering economic activity in other sectors.

[4] Information garnered during discussions with Lero's Director.

Similarly, outputs produced in other sectors of the Irish economy are used by Lero as inputs in its own scientific research. For example, Lero recruits a significant number of PhD students and postdoctoral researchers from the Irish research system, as well as from overseas. In addition, a significant part of Lero's research collaborations with industry partners comes from the in-kind contributions these companies provide through the use of specialised equipment, datasets and software packages.

Lero therefore produces economic activity both by drawing on, and supplying to, the wider Irish economy. Lero also has more than 200 researchers working in a variety of high-tech, high value-added, research-intensive jobs[5]. The salaries of Lero researchers filter back into the Irish economy through domestic spending, which boosts demand in other sectors of the Irish economy, thus creating more economic activity. Therefore, in assessing Lero's overall contribution to the Irish economy through its expenditure, it is vitally important to use a method of analysis that is able to capture such economic contributions.

In order to assess the overall economic impact of Lero through its expenditure, the key question this report addresses is as follows:

Does the Irish economy receive more that €1s worth of economic activity for every €1 invested in Lero by public funding agencies and industry partners?

To address this question, the report applies an input-output analysis to 13 years of administrative data obtained from Lero (2005-2018). Input-output analysis is a well-established method of assessing the economic impact of individual sectors and institutions, based on their expenditure in the wider economy. The concept of input-output analysis was developed in a seminal paper by Wassily Leontief (1936). Leontief's research formed the basis on which the principles of national accounting were developed. In recognition of this work, Leontief was awarded the Nobel Memorial Prize in Economic Sciences in 1973.

Since its development, input-output analysis has become an important method of assessing the economic impact of Higher Education Institutions (HEIs), both in Ireland (CRANN/AMBER 2016; Zhang et al. 2017; UCC 2018) and internationally (Brownrigg 1973, Wilson and Raymond 1973, Lichty and Jesswein; 1978, Kelly and McNicoll 1997; Kelly et al. 2004; Universities UK 2014; Hermannsson et al. 2013; 2015). In sum, input-output analysis can be described as an impact assessment method, appropriate to fulfilling this report's goal of assessing the economic impact of Lero on the Irish economy through its expenditure.

Section 3: Methodology: Input-output analysis

Input-output analysis is a method of conceptualising the whole economy, by measuring the degree of interdependence between sectors in the economy (Hermannsson et al. 2015; Wang and vom Hofe 2007). Every sector in the economy produces outputs. To produce outputs, each sector must draw on inputs from other sectors (Miller and Blair 2009).

For example, Lero operates within the Education Services sector in Ireland. Lero contributes to this sector's output by producing software research (among many other outputs). The production of software research requires inputs from sectors that produce trained researchers and advanced

[5] Information garnered during discussions with Lero's Director.

computers, as well as many other inputs. Once produced, Lero's software research then becomes an input into companies or institutions in other sectors of the economy. These sectors produce their own outputs, which are used as inputs by other sectors, and so on. In this way, input-output analysis provides a means of thinking about the inter-connectedness of all transactions that take place in the economy, and assessing the role Lero's spending plays in the wider economy.

In an input-output analysis, the overall economic impact of one sector or institution, such as Lero, on the national economy can be assessed by measuring how much this particular sector draws on inputs from other sectors, and how much other sectors draw on its outputs.

To conduct an input-output analysis of this nature necessitates the setting up of a matrix known as an input-output table. An input-output table captures all sectors in the economy in terms of both inputs and outputs and lists how much input from one sector is necessary to produce output in another sector (Scottish Government 2011; CSO 2014; Northern Ireland Statistics and Research Agency 2017). An Input-output framework is developed on "the almost banally simple idea that flows should be registered in a matrix, simultaneously by origin *and* by destination" (Augusztinovics 1995, p. 272). In an input-output table, each sector is represented by a column and a row. Each column represents the inputs that each sector draws on from other sectors to produce output. Each row represents the amount of output derived from providing goods and services to other sectors.

Section 3.1: Input-output tables

In the Irish economy, the Central Statistics Office (CSO) defines 58 distinct sectors for input-output analysis (CSO 2014). To attribute economic activity in Ireland to Lero, it is necessary to disaggregate Lero from these 58 sectors. This disaggregation process is achieved by creating a new row and column in the input-output table that specifically represents Lero (Hermannsson et al. 2010a; 2010b; 2010c; 2018). Lero is part of the Education Services sector (CRANN/AMBER 2016; Zhang et al. 2017). Therefore, by disaggregating Lero from the Education Services sector, the input-output analysis conducted in this report includes 59 distinct sectors in the Irish economy (i.e. 58 sectors as defined by the CSO and the new sector representing Lero).

Section 3.2: Output multipliers

While input-output analysis can demonstrate the degree of interdependence between sectors in the economy, a key aspect of this form of analysis is the calculation of so-called 'multipliers' (Hermannsson et al. 2015). In an input-output analysis, multipliers measure how much output changes in one sector in response to output changes in other sectors (Hermannsson et al. 2015). For example, if the Government increases funding to the Education Services sector by €100 million, and this increases Gross Domestic Product (GDP)[6] by €1 billion, assuming that everything else remains constant, the multiplier in this case will be equal to 10. This means that for every €1 the Government invests in the Education Services sector, it produces €10 of additional economic output. By calculating the output multiplier for Lero, this report assesses the impact of Lero's spending on the overall economy.

Multipliers are useful for estimating the overall economic impact of changes in demand, where demand is defined as the total amount of goods and services purchased in the economy (i.e. every time someone purchases an item, they contribute to the demand for that item). There are two forms

[6] Gross Domestic Product is a monetary measure of the market value of all the final goods and services produced in an economy in a specified time period.

of demand in input-output analysis: 1) inter-sectoral demand; and, 2) final demand arising from household consumption.

Inter-sectoral demand consists of the additional income that an increase in output in one given sector generates in other sectors. For final household demand, firms in sectors experiencing higher levels of inter-sectoral demand are likely to grow and employ more people. Existing employees may also experience higher wages due to increasing competition between firms to attract new employees. More jobs and higher wages mean further increases in demand as more people experience a better financial position to increase their consumption.

Section 3.2.1: Types of Multiplier Effects

There are three distinct multiplier effects (Scottish Government 2011; CSO 2014; Northern Ireland Statistics and Research Agency 2017):

1. **Direct effect:** This is the immediate effect caused by the change in final demand for an output. If there is an increase in demand for an output from one sector, *ceteris paribus*, there will be an increase in the output from that sector as producers react to meet the increased demand. For example, if Lero buys a new set of computers, this will increase the production and supply of computers from companies in other sectors of the economy.
2. **Indirect effect:** This is the effect caused by the consequent changes in intermediate demand. As one sector increases its output in response to demand, *ceteris paribus*, this sector will subsequently need inputs from other sectors. Therefore, other sectors will need to increase their output to produce these new inputs. In the case of Lero purchasing new computers, the companies producing those computers for Lero will, in turn, need to purchase the necessary materials to manufacture the computers.
3. **Induced effect:** This is the effect attributable to the ensuing change in compensation of employees and other incomes, which may, *ceteris paribus*, cause further spending and hence further changes in final demand. In terms of household income throughout the economy, direct and indirect effects will increase as a result of increased employment. A portion of this increased income will be re-spent on final goods and services. Following the example given above, as Lero spends money to buy computers, the producers of those computers will receive this money as payment. While some of the money will be paid to workers as wages, another part of this money will be paid to the suppliers of the materials used in computer production. This money will, in turn, be paid as wages to workers in the companies supplying materials. Therefore, the initial expenditure from Lero contributes to wages in two different sectors. As these wages are spent, overall economic activity increases. In addition, as Lero hires more researchers, these researchers' wages will also increase overall economic activity. In this way, all spending by Lero has 'knock on' effects which induce a range of activities in the wider economy.

Based on these multiplier effects, input-output analysis distinguishes between two forms of output multipliers: *Type 1* output multipliers and *Type 2* output multipliers (Scottish Government 2011).

Type 1 output multipliers capture both direct and indirect effects (i.e. 1 and 2 above). In contrast, *Type 2 output multipliers* capture direct, indirect and induced effects (i.e. 1, 2 and 3 above). For this reason, the vast majority of previous studies argue that Type 2 output multipliers are the most appropriate multipliers to use when assessing the overall economic impact of individual HEIs or research centres

within an economy (see e.g., Universities UK 2014; University of Glasgow 2015; CRANN/AMBER 2016; Zhang et al. 2017; UCC 2018).

It is important to note that input-output analysis captures economic impact only in terms of direct, indirect and induced effects. This narrow definition of economic impact is likely to be partial and incomplete. The contribution of institutions such as Lero to the Irish economy is likely to be multi-faceted, including *inter-alia* human capital, research and development (R&D), and entrepreneurial activity (Felsenstein 1996; Glasson 2003; Huggins and Johnston 2009). However, many of these impacts, and, importantly, their overall contribution to the national economy are difficult to accurately measure and beyond the scope of the current report. As noted in Section 2 above, SFI requires publicly funded scientific research to have a broad (i.e. beyond academia) impact on the whole Irish economy (SFI 2012). Therefore, although input-output analysis will not capture the full range of economic and, moreover, societal impacts produced by Lero, it provides a robust and commonly employed means of estimating Lero's contribution to overall economic activity through its expenditure.

Section 4: Data

To construct an extended input-output table for assessing the economic impact of Lero through its expenditure, this report draws on two data sources. The first source of data is the 2011 input-output table for Ireland, which is collected and published by the CSO (CSO 2014). This is the most recent input-output table available for Ireland. The 2011 input-output table provides a sufficiently detailed picture of the transactions of goods and services by industries and consumers in the Irish economy to facilitate the economic impact assessment undertaken in this report (CSO 2014). The input-output table for Ireland is generated using publicly available data from the CSO's StatBank website.[7]

To disaggregate Lero from the Education Services sector, this report draws on a second source of data: administrative data provided by Lero. By combining both the CSO and Lero data sources, an individual row and column can be created for Lero in the CSO's input-output table. This disaggregation procedure required access to Lero's administrative data on income and expenditure. Data made available by Lero for this report includes income and expenditure data from all nine of Lero's sites based at Irish HEIs. Lero's income derives from research and non-research funding from Irish Government funding agencies, such as Science Foundation Ireland, as well as funding from the EU and, increasingly, funding from industry. This data was collected on a per-grant basis for the 13 year period from 2005-2018 drawn from Lero's administrative records.

Drawing on the administrative data provided by Lero, income and expenditure were calculated, as presented in Table 1. The upper panel of Table 1 presents the distribution of total income from its different sources (in percentages) for the years 2005-2018. The lower panel of Table 1 presents the total expenditure categories for the same period (in percentages). As Table 1 shows, the year 2007 represents an unusual income and expenditure composition in relation to the other years in the data. This corresponds to the construction of Lero's main building at the University of Limerick.

[7] The 2011 input-output for Ireland table can be generated by selecting the *Symmetric Input-Output Table of Domestic Product Flows by Output Product Supply, Year and Input Product Supply* option in the following link, and then selecting all 'Input Product Supply' and 'Output Product Supply' options. The final table produced will be a 68x67 matrix, because this table includes a variety of column and row totals for each sector: https://www.cso.ie/px/pxeirestat/database/eirestat/Supply%20and%20Use%20and%20Input%20Output%20Tables/Supply%20and%20Use%20and%20Input%20Output%20Tables_statbank.asp.

Table 1: Total Income and Total Expenditure for Lero by Sources, in Percentage (2005-2018)

Source/Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Period Average
Income															
Income From Ireland (Research)	91.03	71.70	23.01	62.75	64.59	65.63	62.65	72.39	67.27	63.96	66.12	55.73	45.83	54.12	57.25
Income From Outside Ireland (Research)	5.78	8.94	3.19	11.55	13.35	16.65	16.57	14.54	15.66	12.57	15.11	21.44	30.50	23.47	16.67
Income From Ireland (Non-Research)	3.19	19.36	73.80	25.70	22.06	17.72	20.19	10.80	15.21	19.20	15.69	14.10	13.00	11.17	21.75
Income From Outside Ireland (Non-Research)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Industry From Ireland (Research and Non-Research)	0.00	0.00	0.00	0.00	0.00	0.00	0.59	2.27	1.86	4.28	3.08	8.73	10.67	11.25	4.33
Total Income from Industry From Outside Ireland (Research and Non-Research)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Income	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Expenditure															
Salaries	62.50	54.96	21.84	59.58	61.84	62.70	61.75	66.85	65.74	62.66	66.83	63.38	64.55	39.28	58.18
Total Purchases from organisations within Ireland (Domestic Expenditure)	28.88	34.68	60.18	31.12	29.39	28.72	29.45	25.53	26.38	28.76	25.54	28.20	27.29	46.76	32.21
Total Purchases from organisations outside Ireland (Imports)	8.63	10.36	17.98	9.30	8.78	8.58	8.80	7.62	7.88	8.59	7.63	8.42	8.15	13.97	9.62
Total Direct Expenditure	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70	98.70
Taxes Minus Subsidies	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Total Expenditure	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100.0**

Section 4.1: Data assumptions

Lero has nine sites based on the campuses of Irish HEIs in Dublin City University, Dundalk Institute of Technology, IT Tralee, NUI Galway, Maynooth University, Trinity College Dublin, University College Cork, University College Dublin and the University of Limerick, where it is headquartered. As such, each Lero site operates within the administrative structures of the HEI where it is based. Therefore, administration and procurement tend to be centralised in these HEIs and not directly managed by Lero. This means that it was not feasible to access data in the granular form as presented in Table 1 for indirect costs (i.e. overheads) and for several of the expenditure categories (e.g., total purchases, imports and exports). Therefore, a number of assumptions were required to derive the disaggregated input-output table for Ireland that includes Lero as a separate sector. These assumptions are presented below:

- As noted earlier, Lero provided access to 13 years of administrative data which facilitates the creation of a new row and column in the CSO's input-output table for Ireland, thus disaggregating Lero from the Education Services sector. However, the CSO does not publish input-output tables annually. Therefore, the report *takes the 2011 input-output table for Ireland and uses it as a proxy for each of the 13 years.* Most national statistical agencies do not publish input-output tables annually and this has necessitated an input-output table for one year being used as a proxy for multiple years as is also commonly applied in other similar studies (see e.g., CRANN/AMBER 2016; UCC 2018).
- In order to *account for inflation*, all income data from Lero was adjusted to 2011 prices using the GDP deflator for each year, obtained from The World Bank.[8]
- Income data for Lero mainly consisted of direct costs for each grant awarded to Lero from 2005-2018. However, data on overheads was not available from Lero. This is because overheads are managed by each of the Lero HEIs, instead of directly by Lero. To account for this, the percentage rate for overheads for each funding agency and the number of grants awarded by each funding agency across the years of the study were calculated. The average overhead rate was calculated at 30% of total direct costs. Therefore, based on this calculation, *this report assumes a 30% overhead rate for Lero*. The total amount derived from this percentage was added to the figure for total direct income for each year.
- The majority of the grants that Lero receives are for multi-year projects. However, *data is not available on how much of any multi-year grant is used in any given year*. *Therefore, the total amount of the grant was divided equally across the number of years it was awarded for*. For example, if Lero received a research grant for €5 million in 2005 for a period of 5 years, then €1 million will be recorded as being used for each year from 2005-2010. Assuming this was the only grant in that period, total income would be calculated by adding 30% of €1 million for each year as the overhead.
- While detailed income data was provided by Lero for this study, expenditure data for each year was not available. Therefore, Lero personnel reviewed a sample of their largest grants (i.e. research and non-research grants from national and EU funding agencies) and concluded that, on average, approximately 93% of total income from grants is spent (including the

[8] The GDP deflator data used in this report can be accessed via the following link: https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS.

salaries paid to researchers being awarded the grant). Based on this calculation, this report *assumes that annual expenditure is equal to 93% of income from grants*. The remaining 7% is assumed to be operating surplus, as this is how unspent funds are typically accounted for in input-output analyses (see guidelines in CSO, 2014).[9]

- Data on the €-value of imports for each year was not available. Given that Lero is headquartered at the University of Limerick (UL), this report *uses the percentage of imports from total expenses for UL as a proxy for Lero's imports*. The data on UL's imports are drawn from Zhang et al. (2017, p. 1609), who assess the economic impact of Irish HEIs, and calculate UL's imports at 23% of total purchases.
- Data is *not available regarding the total taxes paid minus subsidies received*. In their input-output analysis of the economic impact of Irish HEIs, Zhang et al. (2017) faced the same issue, as data was not available on taxes paid by any of the Irish HEIs. Zhang et al. (2017, p. 1609) used a proxy for taxes minus subsidies by calculating the figure of 1.3% for the Education Service sector as whole and assumed this figure holds for all Irish HEIs. Therefore, this report *uses the figure of 1.3% for taxes minus subsidies.*

Section 4.2: Calculating multipliers for Lero

This section calculates two multipliers for Lero, the first is a Type 2 output multiplier and the second is a Type 2 employment multiplier.

Section 4.2.1: Type 2 Output Multiplier for Lero

The output multiplier refers to the change in total output for the economy as a whole resulting from a unit change in final demand (Hermannsson et al. 2015). The first necessary step in calculating the Type 2 *output multiplier* is to estimate the following model, shown in Equation (1):

1. $$L = (I - A)^{-1}$$

In Equation (1), *L* is the Leontief inverse matrix. *I* is the identity matrix and *A* is the direct requirement matrix. The Leontief inverse matrix is a matrix including the change in output for each sector resulting from a unit change in final demand of one sector. The direct requirement matrix, *A,* represents the total inputs required to produce 1 unit of output. This is obtained by dividing each cell of each column of the input-output table (i.e. sectors) by the column's total. The identity matrix, *I*, is the same size as the direct requirement matrix *A,* but with all cells containing a 0 apart from the central diagonal, which contains all 1's for all sectors. To obtain *L*, the matrix obtained after subtracting the *A* from *I* is then inversed using matrix algebra.

To obtain these matrices, this report first started with the CSO's 2011 input-output table for Ireland (CSO 2014). Lero was then disaggregated from the Education Services sector by calculating the percentage of total output that is spent on each sector (in a new column), and then multiplying by the total income amount derived from Lero's data. The next step was to create a new row for Lero where all sources of income were introduced. The vast majority of Lero's income is derived from national Government sources and the EU. Therefore, each cell in the input-output table for the Lero row

[9] It is important to note that, in some cases, these unspent funds are returned to the funding agency. To account for this, this report runs a second model where total income is reduced by 15%. Results in this second model are consistent with treating the 15% as operating surplus. These results are available by request from the report's authors.

contains a zero in the intersection with other sectors (this was recorded in the cell specified for income from Government).

However, it should be noted that a proportion of Lero's income comes from industry sources. Since 2015, SFI has required that 30% of Lero's funding comes from industry. This SFI requirement did not exist in the years 2005-2015. Therefore, over the total period 2005-2018, industry income is calculated to be approximately 4.33% of total income.[10] This additional income raises Lero's total income to €98.69 million when including both the 95.67% of income from public sources (i.e. €94.42 million) and the 4.33% from industry (i.e. €4.27 million).

Estimating Equation (1) with this extended input-output table would yield Type 1 multipliers. However, as noted above, assessing the overall economic impact of Lero (which includes direct, indirect and induced effects), requires Type 2 multipliers. Therefore, the second necessary step required to obtain Type 2 multipliers involves adding a new column for total household consumption and a new row for total compensation of employees to the matrix. This enables accounting for the induced effect derived from household consumption. Thus, the final matrix consisted of 60 sectors (i.e. the original 58 sectors as defined by the CSO, one sector that was added to disaggregate Lero from the Education Services sector, and one final sector for household consumption).

Finally, the Type 2 multipliers for each sector are obtained by adding all the coefficients for each sector (i.e. the columns' total of the inversed matrix) as follows:

2. $$(O_{mul})_j = \sum L_{ij}$$

In Equation (2), *O* is the output multiplier which is equal to the column total of the Type 2 multipliers for each sector, denoted by the letter *L* (i.e. the Leontief inverse matrix).

Section 4.2.2: Type 2 Employment Multipliers for Lero

In addition to the Type 2 output multiplier described above, this report also calculates Type 2 *employment multipliers*. Employment multipliers allow for the calculation of the number of jobs created directly and indirectly in the economy by Lero. Employment multipliers are calculated via a two-step process, as described below.

Step 1: The induced employment multiplier is calculated by multiplying each cell of the column for each sector's Type 2 output multiplier by the full-time equivalent employment (FTE) data available for each year (from the CSO). The FTE indicates the amount of output in the whole economy that is necessary to create one full-time position. Induced employment means the jobs that are created in other sectors indirectly by Lero's economic activity. This is described in Equation (3):

3. $$\left(E_{eff}\right)_j = \sum_i W_i L_{ij}$$

In Equation (3), *E* is the Type 2 employment multiplier, *L* is the Type 2 output multiplier for each sector (i.e. the Leontief inverse matrix), and *W* is the FTE.

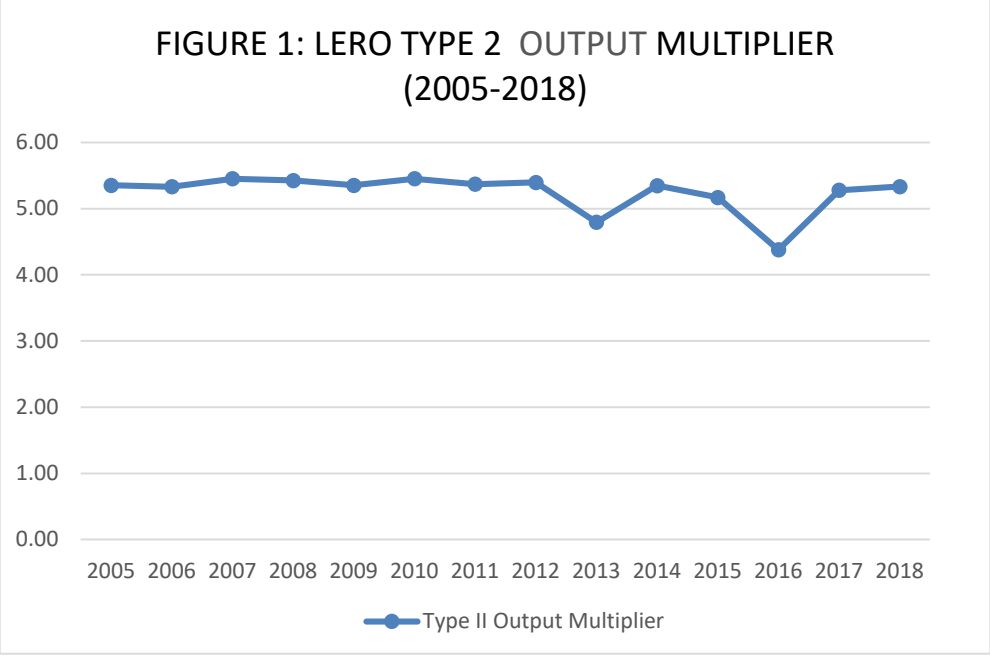
[10] As presented in Table 1, Lero's income from industry has increased since 2015. Due to the methodology employed (where each grant awarded is divided by the number of years corresponding to the grant's duration) industry income generated in 2018 is only partially included in the current study (i.e. only the share of this income for 2018).

Step 2: The induced employment is added to direct employment (i.e. employees working in Lero). This is achieved by deriving a ratio of the total number of jobs created in the overall economy (i.e. induced and direct employment) for each person working in Lero.

Section 5: Results

Figure 1 presents the calculated Type 2 output multipliers for Lero for the period from 2005-2018. The average Type 2 output multiplier for the whole period is 5.25. Therefore, the findings of this report demonstrate that for the period 2005-2018, every €1 invested in Lero by public funding agencies and industry partners contributed €5.25 to the Irish economy on average.

Over the 13 year period, the largest Type 2 multiplier is 5.45. This figure is calculated for the year 2007, which, as outlined in Section 4, was the year that Lero's head office building at the University of Limerick was constructed. The lowest multiplier is 4.38. This figure was obtained for the year 2016, where the induced economic effect is 0.7 points lower than the average effect for the 13 year period. As detailed above, input-output analysis captures expenditure impacts. Moreover, Type 2 multipliers are sensitive to changes in net spending, and to the distribution of total spending between payments for goods and services and payments for salaries. Therefore, although Lero's net spending increased in 2016 from 2015, this expenditure was weighted more towards payments for goods and services. As noted above, 23% of this spending is designated as imports, and is thus not included in the model.



Having obtained the Type 2 multipliers for Lero for each year from 2005-2018, this report now proceeds to derive the overall contribution of Lero's expenditure to the Irish economy (i.e. direct, indirect and induced effects). Table 2 presents Lero's economic impact for each year. Table 2 shows that Lero's initial total income in 2005 totalled €1.33 million. Considering that the Type 2 multiplier for 2005 is 5.35, the overall contribution of Lero's expenditure in 2005 was €7.11 million to the Irish economy. Repeating this process for each year and then adding up the total, as presented in the final row of Table 2, shows that: *With a total income of €98.69 million from 2005-2018, Lero generated a gross output nationwide of €515.32 million during this period.*

Table 2: Lero's Total Economic Contribution (Direct, Indirect and Induced) to the Irish Economy for the period 2005-2018.

Year	Total Income from Lero (€ Million)	Type 2 Output Multiplier	Total Lero's contribution to Irish Economy (€ Million)
2005	€ 1.33	5.35	€ 7.11
2006	€ 3.15	5.33	€ 16.80
2007	€ 10.55	5.45	€ 57.53
2008	€ 4.50	5.43	€ 24.41
2009	€ 5.53	5.35	€ 29.57
2010	€ 6.10	5.45	€ 33.27
2011	€ 5.76	5.37	€ 30.91
2012	€ 8.28	5.40	€ 44.70
2013	€ 7.73	4.79	€ 37.06
2014	€ 5.80	5.35	€ 31.00
2015	€ 6.76	5.17	€ 34.92
2016	€ 8.88	4.38	€ 38.89
2017	€ 10.66	5.28	€ 56.25
2018	€ 13.67	5.33	€ 72.88
Total	**€98.69**		**€515.32**

Table 3: Lero's Contribution to Employment Creation (Number of Equivalent Full-time Jobs)

Year	Total Income from Lero (€ Million)	Employment Multiplier	Induced Employment (Number of Jobs)	Direct Employment by Lero	Total Employment Generated By Lero
2005	€1.33	10.51	14	20	34
2006	€3.15	10.46	33	22	55
2007	€10.55	10.70	113	32	145
2008	€4.50	10.66	48	56	104
2009	€5.53	9.55	53	72	125
2010	€6.10	9.25	56	86	142
2011	€5.76	9.10	52	148	200
2012	€8.28	8.81	73	184	257
2013	€7.73	7.97	62	176	238
2014	€5.80	8.89	52	154	206
2015	€6.76	8.59	58	185	243
2016	€8.88	7.28	65	209	274
2017	€10.66	8.77	93	226	319
2018	€13.67	8.86	121	215	336
Total	**€98.69**		**893**	**1785**	**2678**

Table 3 presents Lero's Type 2 employment multiplier for each year for the period from 2005-2018. The average Type 2 employment multiplier for the whole period is 9.24. The total number of jobs in the Irish economy that are attributed to Lero's economic activity can be shown by the following example. In the first row of Table 3, for 2005, Lero received €1.33 million from public funding agencies and industry partners. Spending this income on salaries and in other sectors of the economy produced an employment multiplier of 10.51. This means that every €1 million invested in Lero by public funding agencies and industry partners produced 10.51 jobs in the economy. Multiplying total funding received in 2005 by the 2005 employment multiplier shows that Lero's economic activity generated 14 additional jobs in the wider Irish economy. In 2005, 20 people also worked in Lero. Therefore, a total of 34 jobs can be attributed to Lero for 2005 (i.e. direct employment and induced employment).

From 2005-2018, total employment generated by Lero was 2,678 jobs nationally. In other words, for every person working in Lero, 1.5 jobs are generated nationwide, including direct employment attributable to Lero and induced employment in the wider economy through Lero's spending.

Section 6: Interpretation of results

This report investigated the overall economic contribution of Lero, the Irish Software Research Centre, to the Irish economy. Over the 13 year period from 2005-2018, Lero received €94.42 million from national funding agencies including Science Foundation Ireland and internationally from the EU, as well as €4.27 million from industry funding. On this basis, the report has sought to answer the following question:

For every €1 invested in Lero by public funding agencies and industry partners, does the Irish economy receive more than €1 worth of economic activity?

Applying an input-output analysis, this report calculated the direct, indirect and induced effects of Lero's expenditure on the Irish economy. Results from this analysis indicate that, on average: *Every €1 invested in Lero by public funding agencies and industry partners contributed €5.25 to the Irish economy*. This means that, with a total income of €98.69 million from 2005-2018, €94.42 million of which came from public funding, *Lero generated €515.32 million for the national economy*.

Section 7: Conclusion

This report assessed the economic impact of Lero, the Irish Software Research Centre, on the Irish economy using input-output analysis. This assessment was undertaken by developing a disaggregated input-output table for Ireland, where Lero was treated as a separate sector in the Irish economy, in order to assess the overall economic contribution of its expenditure.

It should be noted that input-output analysis has a long pedigree as an economic impact assessment method. As highlighted in the literature discussed above, there has been a notable increase in the use of input-output tables in a wide range of empirical studies in the last decade. This can partly be attributed to the improved availability (and quality) of input-output tables, coupled with modern Information Technology (IT) capabilities, thereby facilitating more complex analyses to be undertaken by more researchers.

However, it should also be noted that, as alluded to earlier in the report, research centres such as Lero have key roles to play in economies which go far beyond those that can be identified by input-output analysis. Input-output analysis is focused on the ripple effects of a research centre's expenditure in

the wider national economy. More holistic evaluation frameworks (Lenihan 2011)[11] are required to capture research centres' impacts that go beyond those identified by input-output frameworks. Research centres' have other functions and impacts, such as transmitting knowledge and research, the role played in the socio-economic fabric of the areas in which they are located, and improvements in a population's level of education and training. These other functions and impacts, in turn, impact the economy and society more broadly *vis-à-vis* productivity, employment, economic growth and social wellbeing. The challenge of more holistic impact evaluation approaches is that they are less easily measured and quantified.

Whilst acknowledging the above limitations, it should also be acknowledged that assessing Lero's economic contribution to the Irish economy by means of input-output analysis augments more traditional performance and impact measures for research centres, such as academic publications and industry spin-outs. This contributes to understanding the extent to which Lero fulfils SFI's (2012) requirement that publicly funded research should have an impact on the wider economy.

It should also be noted that the output multipliers obtained for Lero in this report are relatively high in comparison to studies of HEIs outside of Ireland (see e.g., Kelly and McNicoll 1997; Kelly et al. 2004; Universities UK 2014; Hermannsson et al. 2013; 2015). However, output multipliers of similar size are obtained by Zhang et al. (2017) in their analysis of the overall economic impact of Irish HEIs (see also UCC 2018). All of this is stated with the understanding and acknowledgement that HEIs and research centres are not directly comparable. HEIs are larger institutions that fulfil more full service functions in addition to research (e.g., greater teaching and administrative/service functions). However, research centres and HEIs share important characteristics within higher education that permit a reasonable comparison. In the realm of Irish HEIs, the output multipliers obtained in this report are of a similar size to those obtained by CRANN/AMBER (2016) in a report of two SFI Research Centres (i.e. Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN), and Advanced Materials and BioEngineering Research (AMBER)).

In looking to future studies, it would be interesting to compare Lero's performance against other similar software research centres globally, some of which are older and in receipt of greater funding than Lero. As outlined in Section 1 above, a bibliometric analysis of academic publications and citations conducted internally by Lero showed that Lero researchers performed well relative to researchers based at comparable international research centres. It would be interesting to conduct an input-output analysis for similar research centres to Lero, in order to benchmark the scale of Lero's economic contribution.

Lero's economic activity has contributed to the creation of 2,678 jobs nationally. The employment multipliers obtained in this report range between 7.28-10.7. These employment multipliers are of a somewhat higher magnitude *vis-a-vis* those reported in Zhang et al. (2017, p. 1617) for Irish HEIs (4.45-8.84). However, Lero's Type 2 employment multipliers are lower than those reported for the CRANN and AMBER SFI Research Centres (CRANN/AMBER 2016, p. 5), which range between 4.48-19.65.

[11] Note that Lenihan (2011), although applied to the case of enterprise policy evaluation, makes some key points regarding developing and populating holistic evaluation frameworks that can readily be applied to research centres.

CRANN/AMBER (2016) attributes these large employment multipliers to a particularly high ratio of funding relative to headcount in both research centres.

However, caution should be exercised in making any direct comparisons between HEIs and research centres, or when comparing different research centres that have a very different research focus (i.e. Lero versus CRANN/AMBER). While the multipliers obtained by previous studies for HEIs and research centres in Ireland (e.g., CRANN/AMBER 2016; Zhang et al. 2017; UCC 2018) provide a context for the findings of this report, they should not be viewed as a direct comparison.

In summary, this report finds that Lero has made a made a significant economic contribution to the Irish economy. Moreover, the results presented in this report represent an example of the wider economic benefits of investing in publicly funded scientific research.

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