EXPLORING INDUSTRY 4.0 PRODUCTION IN SWEDEN

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Abstract [92 words]

Like many industries before it, manufacturing is being reshaped by new technology. Much existing analysis on the Fourth Industrial Revolution or 'Industry 4.0' has focused on *users* and more broadly, on awareness and levels of readiness in existing businesses In contrast, we look at the evolution of Industry 4.0 *producers* in Sweden during the 2000s and early 2010s. We use rich MONA microdata, and provide results both at national level and at municipality level, identifying clusters in Stockholm and other Swedish cities. We identify and discuss a number of distinctive ecosystem features.

1/ Introduction

Like many industries before it, manufacturing is being 'disrupted' by new technology. This 'Fourth Industrial Revolution' (Schwab, 2017) or 'Industry 4.0' (Brettel et al., 2014) promises substantive productivity and growth effects via the application of technologies such as sensors, nanotech, RFID chips, robotics, machine learning and AI to a vast range of industrial settings (Brynjolfsson and McAfee, 2014). The general purpose nature of many of these technologies (Bresnahan, 2010) is said to promote recombinant growth (Kremer, 1993) both through the reconfiguration of existing production lines, products and services, and the development of entirely new ones.

Much of the existing analysis on the Fourth Industrial Revolution and the implications for the so called new manufacturing model called Industry 4.0 has focused on *users* and more broadly, on industry awareness and levels of readiness in existing businesses (Brettel et al., 2014; Lee et al., 2014; Lee et al., 2015; Schwab, 2017). In contrast, in this chapter we look at the evolution of Industry 4.0 *producers*, specifically science and technology companies in Sweden during the 2000s and early 2010s. We use rich microdata from the Swedish MONA dataset to do this, and provide results both at national level and at municipality level, identifying clusters in Stockholm and other Swedish cities.

Sweden is a particularly interesting country to study in relation to what Swedish policy makers call *smart manufacturing*. Its industrial heritage – in particular, its historic strengths in electrical engineering and mobile communications – means that hardware firms can potentially draw on a rich 'ecosystem' of high-value manufacturing knowledge, suppliers and collaborators, and a thick labour market of skilled and experienced workers (Brown and Mason, 2014; Spigel, 2017). Unlike Germany, which combines large conglomerates with the 'Mittelstand' of small and medium-size firms, Sweden's industrial economy remains dominated by large MNEs, plus a cadre of specialist ICT consulting companies (Gens et al., 2015; Giertz, 2015a). Furthermore, in the early 2000s Ericsson shed around 50% of its workforce: many laid-off workers have either started their own businesses, or moved into consultancy roles, diffusing technical know-how further through the economy (Chaminade et al., 2010). Relatedly, Stockholm has become one of Europe's leading technology hubs, with both thousands of young tech companies and some global players such as Skype, Spotify, Mojang and Klarna (Semuels, 2017).

Furthermore, Sweden has a tradition of hands-on industrial policy: national and local policymakers are actively trying to encourage the adoption of new technology across a range of sectors and firm types and a shift towards smart manufacturing. Much of this has been in response to the so-called 'Swedish Paradox' – high levels of R&D spending but low productivity (Bitard et al., 2008; Kander and Ejermo, 2009), which, it was argued, may be partly explained in Schumpetarian terms by a lack of new entrants who bring new ideas to the market (Aghion et al., 2009).

The chapter is organised as follows. Section 2 sets out some key concepts and the country context. Section 3 describes our methodology. Section 4 discusses results. Section 5 gives brief conclusions.

2 / Framework

2.1 / Defining Industry 4.0

'Industry 4.0', the 'Industrial Internet' and the 'Fourth Industrial Revolution' (FIR) are fuzzy terms with no standardised definitions (Giertz, 2015a; Gens et al., 2015). Its components can usefully be seen as a 'technology-product-industry space': that is, an evolving set of technologies, product/service applications and industry specifics.

Commonly cited FIR *technologies* include sensors and radio chips, AI; machine learning; 3D printing, nanotech and cloud computers. Many of these have general purpose characteristics (Bresnahan, 2010; Perez, 2010) and can be applied to a vast range of *products and services* (Brynjolfsson and McAfee, 2014). These include some wholly new or 'recombinant' use cases (Kremer, 1993), such as new 'smart objects' of varying complexity (such as wearables or drones), as well as existing activities (such as automated production lines), computerised/digitised products (such as medical devices) and components (such as airbags). These new products typically require associated *software*, in apps and or other control systems. In any given industry, a range of *services* also builds on these, especially data and analytics around a product (servitisation), consultancy and training.

Almost all manufacturers could be *users* of these new technologies. We focus on the (smaller) set of *producers* – firms whose sole or principle output is a product/products in the FIR technology space, or a service/services derived from such product. In practice, these firms cover a number of industries typically considered as science and technology, but also advanced manufacturing, medicine / pharma, consumer electronics and specialised software / support.

2.2 / From technologies to ecosystems

More broadly, and following Freeman (1991) and Perez (2010), we can place these components in a larger, dynamic ‘technology system’, that is, a set of multiple technologies and its linked network of producers, suppliers, distributors and users. Technology systems benefit from (potentially substantial) internal spillovers. Perez (2010) argues that as *'technologies interconnect and tend to appear in the neighbourhood of other innovations'* [*p187*], innovations in one part of the space tend to induce complementary (e.g. downstream) innovations in other parts. These spillovers are likely to exist in both technology space (e.g. recombinant use cases) and physical space (clusters of firms that interact and learn from each other).

Industry 4.0 producers are knowledge-intensive businesses in which symbolic and physical product and service creation is a central activity. As Mudambi (2008) points out, value creation is mostly created at the upstream and downstream ends of a production function: ICTs, in theory, allow ever finer levels of disaggregation and control. Nevertheless, while the costs of organising across long distances have fallen, the value of physical proximity for complex activity remains high, especially for building relationships, exchanging codified information and observing others (Glaeser, 2011). A number of studies have highlighted tools such as project-based organising (Grabher, 2002), virtual communities (Grabher and Ibert, 2014) and online tools (Bathelt, 2005) to mimic face to face. In general, technology companies *both* make extensive use of these distance-based tools *and* tightly cluster into urban space (Nathan and Vandore, 2014; Martins, 2015).

How these local and non-local organising dynamics work in the Swedish case is an empirical question. In practice, we can observe co-location straightforwardly through structured data; firm-firm linkages and relationships are less easy to see.

2.3 / The Swedish context

Sweden has a deep history of involvement in information and communication technology production, especially electronic engineering, as well as closely related fields in advanced manufacturing (Giertz et al (2015a, 2015b), from which this account draws heavily). Sweden industrialised late compared to European rivals, but then developed very rapidly, particularly in telecoms: by 1855, for example, there were 5,000 telephone sets in Stockholm, the highest in the world at that time.

In the first half of the twentieth century, Sweden's ICT and manufacturing industries developed through a corporatist national policy framework, with private companies and the state co-creating key technologies and infrastructure, acting as developer and lead customer respectively. Some of these industrial policy bets worked out better than others: the Swedish personal computer industry faded away in the 1980s, for example, but the mobile communications industry did better. By 1969 a common Nordic mobile system had been developed; by 1985 Nordic Mobile Telephony (NMT) was the world's largest mobile network. The pan-European GSM standards group was formed in 1982, with Swedish companies heavily involved in developing the standard for its eventual launch in 1991: it subsequently became a global benchmark for telecoms, helping establish Ericsson as a global ICT player.

The corporatist policy framework, already under political attack in the 1970s and 1980s, was rolled back substantively during the 1990s after a fiscal crisis, when a number of pro-competition and pro-entrepreneurship policies were also introduced. In 1995 Sweden joined the European Community and deregulated energy, telecoms, postal services and the media, further altering its nationalised / corporatist economic development model.

The early 2000s saw Ericsson, the country's largest ICT firm, enter a period of crisis, driven by the dotcom crash and strategic miscalculations in 3G technology. By 2004 it had shrunk around half its workforce, with large job losses in Sweden. These company-level shifts had important knock-on effects in the country. Many laid-off engineers moved into hardware engineering, finance or banking, triggering a wave of entrepreneurship across ICT, especially software and the Internet.

In parallel, public policymakers in Sweden introduced a number of measures to support new firm formation in technology and other sectors. A policy consensus gradually grew on the need to raise levels of entrepreneurship in the country, especially in high-value activity. A number of subsequent reforms in the 1990s and 2000s – to tax and competition policy, for example – appear to have helped develop the country's entrepreneurship culture (Semuels, 2017). A national programme also provided subsidised PCs to households, with employers sharing costs; this widely diffused computers into society, including to households that otherwise would have been unable to afford them. Vinnova, the national innovation systems agency, was founded in 2001, as part of a major reorganisation of national economic development institutions. It takes a major interest in Industry 4.0, aiming to connect traditional industries to new digital processes, and tools, especially in export industries.

3/ Methodology

Our quantitative analysis uses microdata from the Statistics Sweden MONA database for the years 2007-2012 inclusive. We build industry and municipality-level panels from firm and worker-level microdata. The industry-level panel consists of 3,583 4-digit industry*year observations for 2007-2012. The municipality-level panel consists of 1,752 area*year observations for the same time period. Further details of the build are available on request.

To identify the set of tech firms that are Industry 4.0 producers, we start with a set of 'science and tech' industries drawn from an international benchmarking exercise conducted by the UK Office of National Statistics (Harris, 2015) and defined using 5-digit SICs. Drawing on the framework above, we refine this to proxy 'Industry 4.0' producer sectors, dropping a number of content activities (publishing, media, music, advertising) and science /health activities (life sciences, health) except where SIC descriptors directly pertain to R&D and/or manufacturing. We then crosswalk this to 4-digit SICs, which is identical to the NACE Rev 2 /SNI07 codes used in Sweden and other EU states.

We also select a set of STEM occupations from NESTA (Bakhshi et al., 2015), crosswalking these from UK SOC2010 occupation codes to SOC2008, then to the international ISCO08 and ISCO88 standards. The latter is identical to the SSYK-96 codes used in the Swedish data. Final lists of industries and occupations are given in the appendix, in Tables A1 and A2 respectively.

4/ Results

Table 1 compares mean characteristics for the set of Industry 4.0 producing industries against the rest of the economy, pooled across 2007-2012. The right hand column gives the result of a two-tailed T-test on means. We compare across a range of key characteristics in Panels 1 and 2.

Table 1. Industry 4.0 producers in Sweden: distinctiveness.

Variable	I4.0	Rest	Different?
Total firms 5 years old or less	273.221	420.884	Y
Total large firms	2.161	1.628	Y
Total SMEs	882.073	1,582.661	Y
Total value added (mSEK)	3,579.333	3,211.102	N
Total net turnover (mSEK)	13,017.630	11,681.930	N
Total exports value (mSEK)	4,181.818	1,694.266	Y
Total patents weighted by applicants	13.830	3.012	Y
Total employment	4,395.439	4,209.906	N
Number of tertiary educated employees ≤ 3yrs	826.717	636.933	Y
Number of tertiary educated employees > 3yrs	1,396.159	783.519	Y
Total STEM workers	954.285	250.847	Y
Average science workforce intensity	0.013	0.010	Y
Average engineering workforce intensity	0.015	0.006	Y
Average tech workforce intensity	0.037	0.013	Y
Average stem workforce intensity	0.065	0.029	Y

Source: Statistics Sweden.
Notes: graduates are those with 3 years or less tertiary education; + postgrads adds in those with more than 3 years tertiary education; STEM occupations defined from NESTA (2015); Intensity = share of workers in science / engineering / tech / stem occupations, compared to all workers in these industries; Tech industries defined using Harris (2015); Turnover, value, added, exports value given in mSEK; Patents weighted by applicants. Difference = two-tailed t-test, 5% significance or better.

We can see that in almost all key characteristics, including workforce mix, these industries differ from the rest-of-industry average. Notably, while these industries produce substantively more patents than the rest of Sweden (and cover over 75% of all Swedish patenting, see Table 2), and generate substantively higher exports, overall value added and turnover are not significantly different from other Swedish industries. This provides some support to the notion of the Swedish Paradox. We can also see that compared to non tech-industries, 'sci-tech' and Industry 4.0 production has significantly more large firms, fewer start-ups and fewer small and medium-size enterprises (SMEs).

Importantly, in Panel 3 we compare on the basis of STEM workforce 'intensity' and its component parts. This last borrows the concept of 'creative intensity' widely used in creative economy analysis (Bakshi et al, 2015). This defines a set of 'creative occupations' and then looks at how 'intensively' these are used across different industries. For a given industry *i*, creative intensity is defined as the share of workers in creative occupations in industry *i* out of all workers in *i*. Here, we substitute creative occupations for scientists, engineers, tech workers and the aggregate set of STEM workers. Again, we can see that Swedish Industry 4.0 producers are distinctive from the rest of Swedish firms in their use of scientists, engineers and technical staff.

Table 2 shows the main characteristics of the Industry 4.0 production sectors – and covers the period 2007-2012 inclusive.

The top panel looks at workforce characteristics, the middle and bottom panels cover firm characteristics. For each panel, we show totals by year, percentage change over the period, and these sectors' share of activity across all workers / all firms, accordingly. We can see that in 2012, these sectors employed around 18% of all workers (top panel). Skilled workers make up a disproportionate share of this (these industries employ 21.6% of all graduates, and just under 30% of all workers with postgraduate qualifications). Not surprisingly, over 2/3 of the country's workers in STEM jobs are employed in these sectors. While these industries' overall workforce share has fallen slightly between 2007 and 2012, shares of skilled and STEM workers have risen, often substantially.

Industry 4.0 production comprises just under 10% of all firms in Sweden (middle panel). This set of industries has grown by 17% since 2007 and its composition has changed, with a big rise in SMEs and startups but a fall in large firms (those with over 250 staff). Nevertheless, the sector still contributes over a fifth of all large firms in Sweden. In terms of broader economic performance (bottom panel), turnover, value added and exports are all on an upward trend – but strikingly, patenting, a key innovation measure, has fallen since 2007.

Table 2. Industry 4.0 producers in Sweden: time trends.

	Workers	**Graduates**	**+ Postgrads**	**STEM workers**
2007	464,683	85,516	135,288	90,503
2008	476,401	86,365	141,980	97,519
2009	455,653	84,132	143,814	99,395
2010	445,812	85,646	147,129	100,925
2011	459,503	88,853	153,370	104,161
2012	462,679	89,493	156,603	107,742
% change 2007-12	*-0.43%*	*4.65%*	*15.76%*	*19.05%*
% all, 2012	*17.73%*	*21.62%*	*29.97%*	*67.02%*
	Firms	**Start-ups**	**SMEs**	**Large firms**
2007	87,425	27,923	86,726	238
2008	90,552	28,274	89,483	237
2009	92,683	28,439	91,395	225
2010	87,493	27,415	85,912	221
2011	101,718	30,102	100,265	218
2012	102,606	29,703	101,043	220
% change 2007-12	*17.36%*	*6.37%*	*16.51%*	*-7.56%*
% all, 2012	*9.68%*	*11.40%*	*9.67%*	*22.00%*
	Turnover	**Value added**	**Exports**	**Patents**
2007	390,990	1,394,861	443,986	1,767
2008	376,374	1,427,239	459,208	1,690
2009	319,548	1,191,571	356,198	1,504
2010	381,274	1,260,775	410,137	1,677
2011	400,075	1,465,458	495,151	1,518
2012	383,141	1,448,182	465,684	
% change 2007-12	*-2.01%*	*3.82%*	*4.89%*	*-14.04%**
% all, 2012	*19.57%*	*18.67%*	*45.57%*	*76.93%**

Source: Statistics Sweden.
Notes: Tech industries defined using Harris (2015); graduates are those with 3 years or less tertiary education; + postgrads adds in those with more than 3 years tertiary education; STEM occupations defined from NESTA (2015); startups defined as firms 5 years old or less; Turnover, value, added, exports value given in mSEK; Patents weighted by applicants; * change and national shares given for 2011.

Our analysis resonates with that of Giertz et al (2015a) who classify Swedish ICT firms into eight cross-sector verticals. However, they focus on a much narrower range of established ICT firms (2700 companies that have over five employees) compared with our sample. Within this smaller set, the ‘hardware components’ and ‘complete systems’ ‘verticals’ (closely related industry sets organised around common technologies, products or services) comprise around 14% of firms and over 20% of all ICT sector staff (over 26,000 of 132k FTE in 2011, compared with 459k in our data).

As in our ICT-wide data, hardware activity is a mix of a few large incumbents, plus a long tail of SMEs. The complete systems vertical is dominated by a few large incumbents – with under 200 firms in total, of which Ericsson accounts for over 70% of all employees. By contrast, the hardware components vertical is dominated by SMEs, with around 10 employees on average; the few large firms have only a few hundred staff. Many of these firms are ‘contracting manufacturing’. Many of the newer firms are start-ups producing ‘fibre optics, nanotech, power electronics, printed electronics, control equipment, measuring and calibration, antennas, power transistors, alarms, lasers, sensors and actuators’, and many are connected to universities.

The other hardware-relevant component of the Swedish ICT industry is R&D focused consulting, which in Giertz et al (2015a) comprised over 360 established firms and almost 12,400 staff in 2011. These firms work with other tech businesses on ‘pure technical applications’, including an important subset dealing with embedded systems and the Internet of Things. The roots of this consulting sector lie largely in corporate shakeups, as discussed above.

4.2 / Municipality analysis

Swedish Industry 4.0 producers are highly clustered, with Stockholm city and county the largest agglomeration of activity. Tables 3 and 4 give counts, shares and location quotients at municipality level for the years 2007-2012.

Table 3 looks at the 20 municipalities with the largest counts of Industry 4.0 firms. Over a quarter of these are in Stockholm County, with Stockholm municipality having over twice as many firms as the next municipality (Gothenberg), over three times as many

Industry 4.0 producer SMEs and around twice as many employees in these industries. Notably, tech SMEs make up almost all of the population of ICT firms, and between 9 and 18% of all SMEs in these municipalities. Stockholm County comprises around 47% of all Industry 4.0 employment in the 20 most ICT-firm dense municipalities.

Counts and shares do not fully control for areas' underlying economic structure. Table 4 uses location quotients (LQs) to do this, for the 20 municipalities with the highest LQs in 2007-2012. Lund has the highest LQ in Sweden in this period; Stockholm City has a rather lower LQ, reflecting its greater economic diversity. However, Stockholm county dominates the table: just under two-thirds of the Sweden's largest tech clusters are in Stockholm municipalities.

Table 3. Firms and workers, top 20 Swedish municipalities by firm counts, 2007-2012.

Code	Municipality	County	Sci-tech firms		Sci-tech SMEs			Sci-tech workers	
			Total	% all firms	Total	% all SMEs	% all tech	Total	% all workers
0180	Stockholm	Stockholm	17176	13.84	17114	14.04	99.64	121529	17.32
1480	Göteborg	Västra Götaland	6881	14.32	6853	14.51	99.59	64989	32.93
1280	Malmö	Skåne	3096	12.22	3091	12.46	99.84	12496	14.21
0380	Uppsala	Uppsala	2353	13.43	2351	13.64	99.92	6932	21.19
1281	Lund	Skåne	1854	17.90	1850	18.12	99.78	11685	41.25
0580	Linköping	Östergötland	1531	13.83	1529	14.09	99.87	13039	42.65
1980	Västerås	Västmanland	1337	14.11	1332	14.31	99.63	15099	41.55
0182	Nacka	Stockholm	1281	13.82	1279	14.03	99.84	2544	19.59
1283	Helsingborg	Skåne	1231	10.84	1230	11.05	99.92	4202	12.77
0160	Täby	Stockholm	1214	16.95	1214	17.23	100.00	1978	14.70
2480	Umeå	Västerbotten	1030	9.60	1029	9.70	99.90	2042	10.83
0184	Solna	Stockholm	1026	15.74	1022	16.02	99.61	4946	6.19
0163	Sollentuna	Stockholm	1014	17.35	1014	17.63	100.00	1855	11.13
0680	Jönköping	Jönköping	984	9.28	979	9.40	99.49	6291	22.05
0581	Norrköping	Östergötland	948	10.52	946	10.70	99.79	2908	10.33
1880	Örebro	Örebro	889	8.50	888	8.64	99.89	3557	10.67
1384	Kungsbacka	Halland	888	11.43	887	11.59	99.89	1146	12.19
0126	Huddinge	Stockholm	878	12.14	878	12.33	100.00	874	7.42
1490	Borås	Västra Götaland	797	9.01	795	9.12	99.75	4040	17.25
1780	Karlstad	Värmland	783	9.92	782	10.07	99.87	2384	13.57

Source: Statistics Sweden.
Notes: tech industries defined using Harris (2015); startups defined as firms 5 years old or less.

Table 4. Location quotients, top 20 Swedish municipalities by firm counts, 2007-2012.

Code	Municipality	County	Firms	SMEs	Startups	Employees
1281	Lund	Skåne	1.856	10.370	10.187	2.256
0163	Sollentuna	Stockholm	1.802	10.385	10.954	0.608
0160	Täby	Stockholm	1.758	10.386	10.395	0.802
0184	Solna	Stockholm	1.632	10.349	10.447	0.346
1262	Lomma	Skåne	1.603	10.392	9.925	0.984
1481	Mölndal	Västra Götaland	1.601	10.378	9.214	1.054
0183	Sundbyberg	Stockholm	1.571	10.377	11.006	0.688
0123	Järfälla	Stockholm	1.561	10.384	10.796	0.854
1402	Partille	Västra Götaland	1.507	10.392	9.647	0.693
0186	Lidingö	Stockholm	1.485	10.366	10.224	1.588
1480	Göteborg	Västra Götaland	1.484	10.349	10.554	1.793
0162	Danderyd	Stockholm	1.467	10.366	10.025	0.949
1980	Västerås	Västmanland	1.462	10.356	11.426	2.264
0180	Stockholm	Stockholm	1.435	10.354	10.836	0.944
0580	Linköping	Östergötland	1.433	10.375	10.489	2.324
0187	Vaxholm	Stockholm	1.432	10.392	10.923	0.532
0182	Nacka	Stockholm	1.432	10.382	10.687	1.067
0199			1.415	10.392	16.330	0.934
0117	Österåker	Stockholm	1.410	10.392	10.343	0.578
0128	Salem	Stockholm	1.403	10.392	10.122	0.382

Source: Statistics Sweden.

Notes: tech industries defined using ONS / Harris (2015); startups defined as firms 5 years old or les

Other studies confirm this spatial picture. Chaminade et al (2010) point to the Kista cluster of large tech MNEs (including Infosys, Huawei and Lenovo) just outside Stockholm city, as nationally important, alongside Skåne county (for computer games) and Linköping (for web servers). Over half the ICT employment identified by Giertz et al (2015a) is located in Stockholm County[1] – over 60,000 FTE staff, far fewer than in Table 3 above given those authors' very restrictive sampling frame. Six of the eight verticals identified have over half their employees in the area. In hardware systems, Giertz et al (2015a) highlight that Ericsson has always been critically important to the Stockholm cluster – both through its location in Kista and elsewhere in the metro area, and through its system-wide effects across the county and the country as a whole. Notably, the two *least* concentrated sectors identified by Giertz et al (ibid) are the focus of interest in this study. Around 77% of hardware components staff work outside Stockholm county, as do 65% of R&D-related consultancy staff. Stockholm remains the single largest location for these activities, however.

5/ Conclusions

This chapter uses rich microdata to explore Industry 4.0 production in Sweden, a country with both a rich heritage in advanced manufacturing and an activist public policy tradition. Hardware products and services in Sweden can draw on existing ecosystems, especially in electrical engineering and mobile communications. Swedish Industry 4.0 producers comprised around 10% of the country's firms in 2012, but around 20% of all large firms. They employed around 18% of all workers, but 2/3 of the country's STEM workers. These industries are nationally distinctive in their intensive use of skilled and STEM staff, high levels of patenting, turnover and exports. This setting presents both opportunities and challenges for Sweden as it develops readiness for I4.0 (Nathan 2018). Industry 4.0 producers can draw on a rich, perhaps unique, ecosystem of high-value knowledge, a web of potential suppliers and large numbers of skilled, experienced workers, much of which is already co-located in a few urban hubs. Unlike competitors such as Germany, in Sweden these industries are also dominated by a few large firms: there are relatively few start-ups and SMEs, although as we have shown, their numbers are growing rapidly. Large incumbents are a striking feature of the Swedish ecosystem. They

[1] Stockholm County consists of 26 municipalities, out of 290 municipalities, and there are 20 counties in the whole of Sweden.

can act as key buyers of new products and services, and potentially, partners in product / firm development. Historically, corporate shocks to large players – notably Ericsson – has helped feed subsequent growth in new entrants. Conversely, large firms in Sweden have tended towards incremental innovation conducted internally, which may present co-ordination problems for joint ventures. On top of policies to promote entrepreneurship, and the growth of Stockholm as a leading European tech cluster, this suggests that future Swedish industrial policy will also need to look for tools to promote better linkages between emerging and existing industry actors in the national ecosystem.

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Appendix

Table A1. List of sci-tech industries

‘Science and tech’ industries are drawn from an international benchmarking exercise conducted by the UK Office of National Statistics (Harris, 2015). The ONS set of industries is defined at 5-digit SIC2007 level. I refine this to focus on Industry 4.0, dropping a number of content activities (publishing, media, music, advertising) and science /health activities (life sciences, health) except where SIC descriptors directly pertain to R&D and/or manufacturing. We then crosswalk this to 4-digit SIC, which is identical to the NACE Rev 2 /SNI07 codes used in Sweden and other EU states.

NACE	NACE_descriptor	ONS_category
1920	Mineral oil refining	other science_tech manufacture
2000	Manufacture of chemicals and chemical products	other science_tech manufacture
2010	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	other science_tech manufacture
2011	Manufacture of industrial gases	other science_tech manufacture
2012	Manufacture of dyes and pigments	other science_tech manufacture
2013	Manufacture of other inorganic basic chemicals	other science_tech manufacture
2014	Manufacture of other organic basic chemicals	other science_tech manufacture
2015	Manufacture of fertilisers and nitrogen compounds	other science_tech manufacture
2016	Manufacture of plastics in primary forms	other science_tech manufacture
2017	Manufacture of synthetic rubber in primary forms	other science_tech manufacture
2020	Manufacture of pesticides and other agrochemical products	other science_tech manufacture
2030	Manufacture of paints, varnishes and similar coatings, mastics and sealants	other science_tech manufacture
2040	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	other science_tech manufacture
2041	Manufacture of cleaning and polishing preparations	other science_tech manufacture
2042	Manufacture of perfumes and toilet preparations	other science_tech manufacture
2050	Manufacture of other chemical products	other science_tech manufacture

2051	Manufacture of explosives	other science_tech manufacture
2052	Manufacture of glues	other science_tech manufacture
2053	Manufacture of essential oils	other science_tech manufacture
2059	Manufacture of other chemical products n.e.c.	other science_tech manufacture
2060	Manufacture of man-made fibres	other science_tech manufacture
2521	Manufacture of central heating radiators and boilers	other science_tech manufacture
2530	Manufacture of steam generators, except central heating hot water boilers	other science_tech manufacture
2540	Manufacture of weapons and ammunition	other science_tech manufacture
2610	Manufacture of electronic components and boards	digital technologies
2611	Manufacture of electronic components	digital technologies
2612	Manufacture of loaded electronic boards	digital technologies
2620	Manufacture of computers and peripheral equipment	digital technologies
2630	Manufacture of communication equipment (other than telegraph and telephone apparatus and equipment)	publishing and broadcasting
2640	Manufacture of consumer electronics	digital technologies
2651	Manufacture of non-electronic instruments and appliances for measuring, testing and navigation, except industrial process control equipment	other science_tech manufacture
2652	Manufacture of watches and clocks	other science_tech manufacture
2660	Manufacture of irradiation, electromedical and electrotherapeutic equipment	life science and healthcare
2670	Manufacture of photographic and cinematographic equipment	publishing and broadcasting
2680	Manufacture of magnetic and optical media	digital technologies
2700	Manufacture of electrical equipment	other science_tech manufacture
2710	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	other science_tech manufacture
2711	Manufacture of electric motors, generators and transformers	other science_tech manufacture
2712	Manufacture of electricity distribution and control apparatus	other science_tech manufacture
2720	Manufacture of batteries and accumulators	other science_tech manufacture
2730	Manufacture of wiring and wiring devices	other science_tech manufacture
2731	Manufacture of fibre optic cables	other science_tech manufacture
2732	Manufacture of other electronic and electric wires and cables	other science_tech manufacture

2733	Manufacture of wiring devices	other science_tech manufacture
2740	Manufacture of electric lighting equipment	other science_tech manufacture
2750	Manufacture of domestic appliances	other science_tech manufacture
2751	Manufacture of electric domestic appliances	other science_tech manufacture
2752	Manufacture of non-electric domestic appliances	other science_tech manufacture
2790	Manufacture of other electrical equipment	other science_tech manufacture
2810	Manufacture of general purpose machinery	other science_tech manufacture
2811	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	other science_tech manufacture
2812	Manufacture of fluid power equipment	other science_tech manufacture
2813	Manufacture of compressors	other science_tech manufacture
2814	Manufacture of other taps and valves	other science_tech manufacture
2815	Manufacture of bearings, gears, gearing and driving elements	other science_tech manufacture
2821	Manufacture of ovens, furnaces and furnace burners	other science_tech manufacture
2822	Manufacture of lifting and handling equipment	other science_tech manufacture
2823	Manufacture of office machinery and equipment (except computers and peripheral equipment)	other science_tech manufacture
2824	Manufacture of power-driven hand tools	other science_tech manufacture
2825	Manufacture of non-domestic cooling and ventilation equipment	other science_tech manufacture
2829	Manufacture of other general-purpose machinery n.e.c.	other science_tech manufacture
2830	Manufacture of agricultural and forestry machinery	other science_tech manufacture
2840	Manufacture of metal forming machinery and machine tools	other science_tech manufacture
2841	Manufacture of metal forming machinery	other science_tech manufacture
2849	Manufacture of other machine tools	other science_tech manufacture
2890	Manufacture of other special-purpose machinery	other science_tech manufacture
2891	Manufacture of machinery for metallurgy	other science_tech manufacture
2892	Manufacture of machinery for mining, quarrying and construction	other science_tech manufacture
2893	Manufacture of machinery for food, beverage and tobacco processing	other science_tech manufacture
2894	Manufacture of machinery for textile, apparel and leather production	other science_tech manufacture
2895	Manufacture of machinery for paper and paperboard production	other science_tech manufacture
2896	Manufacture of plastics and rubber machinery	other science_tech manufacture

2899	Manufacture of other special-purpose machinery n.e.c.	other science_tech manufacture
2900	Manufacture of motor vehicles, trailers and semi-trailers	other science_tech manufacture
2910	Manufacture of motor vehicles	other science_tech manufacture
2920	Manufacture of bodies (coachwork) for motor vehicles (except caravans)	other science_tech manufacture
2930	Manufacture of parts and accessories for motor vehicles	other science_tech manufacture
2931	Manufacture of electrical and electronic equipment for motor vehicles	other science_tech manufacture
2932	Manufacture of other parts and accessories for motor vehicles	other science_tech manufacture
3000	Manufacture of other transport equipment	other science_tech manufacture
3010	Building of ships and boats	other science_tech manufacture
3011	Building of ships and floating structures	other science_tech manufacture
3012	Building of pleasure and sporting boats	other science_tech manufacture
3020	Manufacture of railway locomotives and rolling stock	other science_tech manufacture
3030	Manufacture of air and spacecraft and related machinery	other science_tech manufacture
3040	Manufacture of military fighting vehicles	other science_tech manufacture
3090	Manufacture of transport equipment n.e.c.	other science_tech manufacture
3091	Manufacture of motorcycles	other science_tech manufacture
3092	Manufacture of bicycles and invalid carriages	other science_tech manufacture
3099	Manufacture of other transport equipment n.e.c.	other science_tech manufacture
3212	Manufacture of jewellery and related articles	other science_tech manufacture
3240	Manufacture of professional and arcade games and toys	other science_tech manufacture
3250	Manufacture of medical and dental instruments and supplies	life science and healthcare
3312	Repair of machinery	other science_tech manufacture
3313	Repair of electronic and optical equipment	digital technologies
3314	Repair of electrical equipment	other science_tech manufacture
3315	Repair and maintenance of ships and boats	other science_tech manufacture
3316	Repair and maintenance of aircraft and spacecraft	other science_tech manufacture
3317	Repair and maintenance of other transport equipment	other science_tech manufacture
5100	Air transport	other science_tech services
5110	Scheduled passenger air transport	other science_tech services

5120	Freight air transport and space transport	other science_tech services
5121	Freight air transport	other science_tech services
5122	Space transport	other science_tech services
5820	Software publishing	digital technologies
5821	Publishing of computer games	digital technologies
5829	Other software publishing	digital technologies
6200	Computer programming, consultancy and related activities	digital technologies
6201	Computer programming activities	digital technologies
6202	Computer consultancy activities	digital technologies
6203	Computer facilities management activities	digital technologies
6209	Other information technology and computed service activities	digital technologies
6310	Data processing, hosting and related activities; web portals	digital technologies
6311	Data processing, hosting and related activities	digital technologies
6312	Web portals	digital technologies
7100	Architectural and engineering activities; technical testing and analysis	other science_tech services
7110	Architectural and engineering activities and related technical consultancy	other science_tech services
7111	Architectural activities	other science_tech services
7112	Engineering activities and related technical consultancy	other science_tech services
7120	Technical testing and analysis	other science_tech services
7219	Other research and experimental development on natural sciences and engineering	other science_tech services
7220	Research and experimental development on social sciences and humanities	other science_tech services
7490	Quantity surveying activities	other science_tech services
8540	Higher education	other science_tech services
8541	Post-secondary non-tertiary education	other science_tech services
8542	Tertiary education	other science_tech services
9511	Repair of computers and peripheral equipment	digital technologies
9521	Repair of consumer electronics	other science_tech manufacture
9522	Repair of household appliances and home and garden equipment	other science_tech manufacture
9525	Repair of watches, clocks and jewellery	other science_tech manufacture

Table A2. List of STEM occupations

STEM occupations are taken from NESTA (Bakhshi et al., 2015). I crosswalk these from UK SOC2010 occupation codes to SOC2008, then to the international ISCO08 and ISCO88 standards. The latter is identical to the SSYK-96 codes used in the Swedish data.

Category	ISCO88	ISCO88_descriptor
IT	1226	Production and Operations Department Managers in Transport, Storage and Communications
IT	1236	Computing Services Department Managers
IT	1316	General Managers in Transport, Storage and Communications
IT	1317	General Managers of Business Services
Science	2113	Chemists
Science	2211	Biologists, Botanists, Zoologists and Related Professionals
Science	2212	Pharmacologists, Pathologists and Related Professionals
Science	2111	Physicists and astronomers
Science	2114	Geologists and geophysicists
Science	2211	Biologists, Botanists, Zoologists and Related Professionals
Science	2212	Pharmacologists, Pathologists and Related Professionals
Engineering	2142	Civil engineers
Engineering	2144	Mechanical engineers
Engineering	2143	Electrical Engineers
Engineering	2144	Electronics and Telecommunications Engineers
Engineering	2149	Architects, Engineers and Related Professionals Not Elsewhere Classified
Engineering	2149	Architects, Engineers and Related Professionals NEC
Engineering	2150	Architects, Engineers and Related Professionals NEC
IT	2131	Computer Systems Designers and Analysts
IT	2132	Computer Programmers
IT	2139	Computing Professionals NEC
IT	2131	Computer Systems Designers and Analysts
IT	2132	Computer Systems Designers and Analysts
IT	2131	Computer Systems Designers and Analysts
IT	2132	Computer Programmers
IT	2139	Computing Professionals NEC
IT	2131	Computer Systems Designers and Analysts
IT	2132	Computer Programmers
IT	2139	Computing Professionals NEC
Science	2211	Biologists, Botanists, Zoologists and Related Professionals
Science	2212	Biologists, Botanists, Zoologists and Related Professionals
Science	1237	Research and Development Department Managers
Science	1319	General Managers NEC
Engineering	2148	Cartographers and Surveyors