Prometheus, 2015
Vol. 32, No. 2, 181–201, http://dx.doi.org/10.1080/08109028.2014.957912

Routledge
Taylor & Francis Group

RESEARCH PAPER

Revisiting the mismatch between formal education in computer science and the software and information services sector: the case of Argentina

Mariano Zukerfeld*

CONICET/ e-TCS/Universidad Maimónides, Virasoro 732, Buenos Aires, Argentina

The Argentinean software and information services (SIS) sector has grown steadily over the last decade. However, academics, policy makers and managers agree that the shortage of computer science (CS) degree-holders has been (and is) jeopardizing future growth. This paper depicts the situation of formal education in CS and related areas in Argentina, providing the necessary basis from which to call into question the assumption that the primary driving force of a powerful SIS sector is CS graduates. After presenting figures of enrollment, graduates and researchers, we find that while it is true that there is a mismatch between the trends of formal education in CS and that of Argentinean SIS, it is not clear at all that the sector is limited because of that. First, international comparisons with the US and the UK show that the proportion of graduates is not necessarily the main driver of a highly innovative SIS sector. Secondly, qualitative sources underline the relevance of informal learning in the acquisition of the software skills actually used by workers. Additionally, the particular evolution of SIS wages could be limiting the inflow of graduates into the sector.

Introduction

The software and information services (SIS) sector is, increasingly, at the core of national systems of innovation. Indeed, SIS is important for every country because it deals with the key factor in expanding productivity gains.[1] In the case of developing countries, there are additional reasons for focusing on the sector (Arora and Gambardella, 2004; UNCTAD, 2012). In Argentina, there is broad consensus about the opportunities the sector might offer to increase knowledge-intensive exports, highly skilled employment and, more broadly, to catch up (Malerba and Nelson, 2011) and join the so-called 'knowledge-based economy' (Chudnosky *et al.*, 2001; Yoguel *et al.*, 2006; López *et al.*, 2010; Dughera *et al.*, 2011; Novick *et al.*, 2011).

Software production for the marketplace began in Argentina in the 1970s. For three decades, the sector grew in the absence of specific government support. Although the local market flourished in the 1990s together with the diffusion of personal computers (PCs) and the Internet, the Argentinean devaluation of 2002 was a turning point. From then on, the upsurge in sales, employment and especially export performance became apparent. In 2004, the so-called 'software law' was enacted to foster the sector (Ginsberg and Silva Faide, 2009; Gajst, 2012) and various strategic plans for the sector have been developed in recent years.[2]

*Email: marianozukerfeld@e-tcs.org

Despite its promise, the SIS sector in Argentina faces some obstacles. The availability of qualified human resources has been identified by stakeholders of the sector time and time again as the main obstacle. The term 'qualified human resources' is always translated as computer science (CS) degree-holders (Yoguel *et al.*, 2006; López *et al.*, 2010; OPSSI, 2010; SPEI, 2012). Nevertheless, the literature still lacks a systematic account of formal education in CS in Argentina. This applies not only to present and historical statistics of students, graduates and researchers, but also to international comparisons and the relationship with the labor market.[3]

However, the main problem is not the statistics themselves, but the fact that the possession of skills is automatically assumed to relate to formal education and, more precisely, to the completion of a degree. Although this translation draws partially on international literature (see for example Arora and Gambardella, 2004, and such models as those of Carmel, 2003), it is ultimately anchored in the common-sense belief that complex knowledge and skills are learned in the university. This assumption is highly questionable, especially for the SIS sector. Zukerfeld (2010) finds a new trend in the US economy, starting in the 1970s: each dollar of the gross domestic product (GDP) is decreasingly related to the amount of certified knowledge active in the labor market. Moreover, evolutionist and neo-Schumpeterian approaches have for some decades been highlighting the relevance of informal ways of learning. Although learning by doing, using and interacting usually refers to the acquisition of skills in the workplace (i.e., *after* achieving a degree and not *instead of*), it offers useful insights to denaturalize the link between a degree-level education and skills acquisition (Jensen *et al.*, 2007; Lundvall and Lorenz, 2007). Research based on qualitative fieldwork in the Argentinean SIS sector finds that programmers (both graduates and dropouts) tend to rank poorly the relevance of formal education, when asked for the origins of their skills (Dughera *et al.*, 2011).

So, what are the statistics for formal education in CS in Argentina? To what extent are CS graduates being hired by the SIS sector? Is the number of graduates a key factor in explaining the differences between the Argentinean SIS sector and that of other countries? Has a shortage of CS graduates been limiting the development of the SIS sector in recent years? Is it appropriate to equate qualified human resources with CS degree holders? More generally, what are the theoretical lessons from the Argentinean case that may be applicable to the SIS sectors of other countries?

This paper looks at formal education in computer science and related areas in Argentina in order to provide the necessary basis from which to call into question the assumption that the primary driving force of a powerful SIS sector is CS graduates. Methodologically, it is based mainly on processing and adapting secondary quantitative data which has not previously been analyzed or published. Additionally, it draws on 24 in-depth interviews with software workers and managers from fieldwork carried out in Buenos Aires in 2010. The paper is organized as follows. It first presents some basic facts about the Argentinean SIS sector. It then deals briefly with data about enrollment and first-year undergraduates in CS. The largest section discusses the figures for graduates. As well as analyzing the data from Argentina, we also make comparisons with the US and the UK. The next section focuses on postgraduate students and researchers. Despite being a small group, these highly qualified individuals may be playing a crucial role in national systems of innovation. After this, the paper presents two complementary explanations for the mismatch between the growth of the SIS sector and stagnation in the numbers of students graduating: (1) the evolution of wages in the SIS sector and (2) the influence of non-formal and informal learning. Finally, the conclusion summarizes our findings.

SIS in Argentina: sales, exports and employment

Measuring anything to do with software is a difficult task. Thus, SIS statistics are not reliable, particularly in developing countries such as Argentina (UNCTAD, 2012, p.33). For instance, in Argentina (and other Latin American countries), many policy makers and even scholars base their judgment on data from chamber of commerce surveys. This kind of data arises from self-selected samples, designed according to the interests of the chambers (biased in favor of big and multinational enterprises), not the interests of any national system of innovation. In spite of being relatively useless for comparisons with the rest of the economy, these data are helpful in analyzing the activities of the major SIS firms (as long as one avoids the *pars pro toto* fallacy).

Figure 1 shows that the SIS sector has been experiencing steady growth over the last decade. Although the trend in exports and sales may be overestimated (it is not adjusted for inflation), data from the World Trade Organization (WTO) also show that Argentina has improved its performance (Table 1). Actually, SIS is the branch of employment (private and registered) that has grown more between 1998 and 2011 than any other sector.[4] Hence there are sound reasons to be enthusiastic about the potential of Argentinean SIS. More interesting data still are shown in Table 2, on Argentinean employment in software production. They are remarkable in both relative and absolute terms.

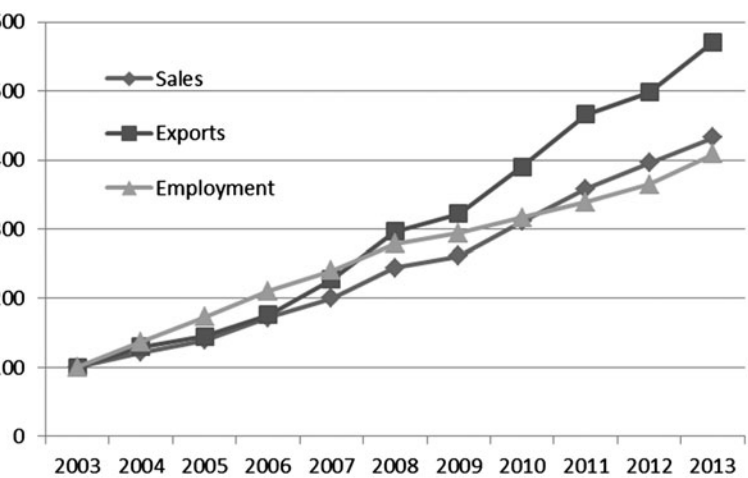

Figure 1. Evolution of sales exports and employment of main software and information services (SIS) enterprises, 2003–2013 (2003 = 100)
Source: OPSSI, 2013. Figures for 2012 and 2013 are estimated. Exports and sales are measured in current US dollars.

Table 1. Top exporting (and importing) countries of SIS, 2010–2011 (US$ billions and %)

Country	Exports (2011)	Imports (2011)	Annual % change (2005–2010)
European Union (27)	101.5*	49.3*	13
(extra-EU)	42.0*	16.7*	18
India	40.5*	2.2*	n/a
United States	9.8	2.2	20
Israel	9.7	n/a	11
Canada	4.1*	1.9*	5
Norway	3.0*	1.6*	27
Philippines	2.0	n/a	85
Russian Federation	1.6	2.1	28
Argentina	1.6	0.5	39
Costa Rica	1.5	n/a	37

Source: WTO (2012).
*2010 data.

Table 2. Branch of activities with higher relative growth and total employment in 2011 (Argentina, 2011/1998, private and registered employment)

Branch of activity	Employment growth (2011/1998, %)	Employment (2011, total)
Software and information services	486	94,883
Mining of metal ores	439	9515
Recycling of waste and scrap	383	4016
Waterborne transport	259	9538
Office machinery	251	3287
Temporary employment agencies	244	83,852
Films, radio, TV	226	111,172
Cargo handling, storage and warehousing	217	93,425
Research and develoment	215	6627
Extraction of crude oil and natural gas	208	43,675

Source: author's elaboration based on Employment and Corporate Dynamics Observatory (OEDE, 2012).

Table 3. Enrollment and first-year undergraduates in computer science and all degrees, by type of institution (Argentina, 2009)

Institution	Students	All degrees	Computer science degrees			CS/all degrees
			Engineering	Other	Total	
Public	Enrollment	1,312,549	34,081	31,462	65,543	5.0%
	First-year undergraduates	290,137	n/a	n/a	16,572	5.7%
Private	Enrollment	337,601	4,316	11,172	15,488	4.6%
	First-year undergraduates	97,466	n/a	n/a	3943	4.1%
Total	Enrollment	1,650,150	38,397	42,634	81,031	4.9%
	First-year undergraduates	387,603	n/a	n/a	20,515	5.3%

Source: SPU (2010).

Enrollment and first-year undergraduates

In Argentina, there are several kinds of degrees in CS and related areas, available throughout the country. In the public education system, there are three types of degrees: 41 technical or minor degrees (called '*tecnicaturas*'), 12 major or bachelor degrees ('*licenciaturas*') and seven engineering degrees. The largest university by enrollment is the National Technological University (UTN). It offers only two major and four minor degrees in this field, but it has 26 campuses distributed through all the regions of the country.

According to the last available data from the Department for University Policies (SPU), there were 81,031 students of CS in 2009. Some 80% of them were enrolled in public institutions, and software engineering was the most pursued degree. Hence, although there are only a few engineering degrees, there are plenty of students; on the other hand, a lot of minor or technical degrees are offered, but not many students choose them.

Overall, the enrollment in CS and related fields accounts for only 5% of total of higher education students in Argentina. The share of first-year undergraduates is higher in public institutions than in private ones, but the figures are quite modest in both. However, the fact that the share of first-year undergraduates (5.3%) is bigger than the enrollment share (4.9%) could suggest either or both an increase in the relative weight of computer science students in the total enrollment and a higher dropout rate.

The historical series shows that enrollment in the CS field as a percentage of total enrollment has declined both in public and private institutions (Figure 2). From almost 7% in the late 1990s, the ratios dropped to less than 5%. In most of the series, the ratio for private institutions is higher than that for public ones. However,

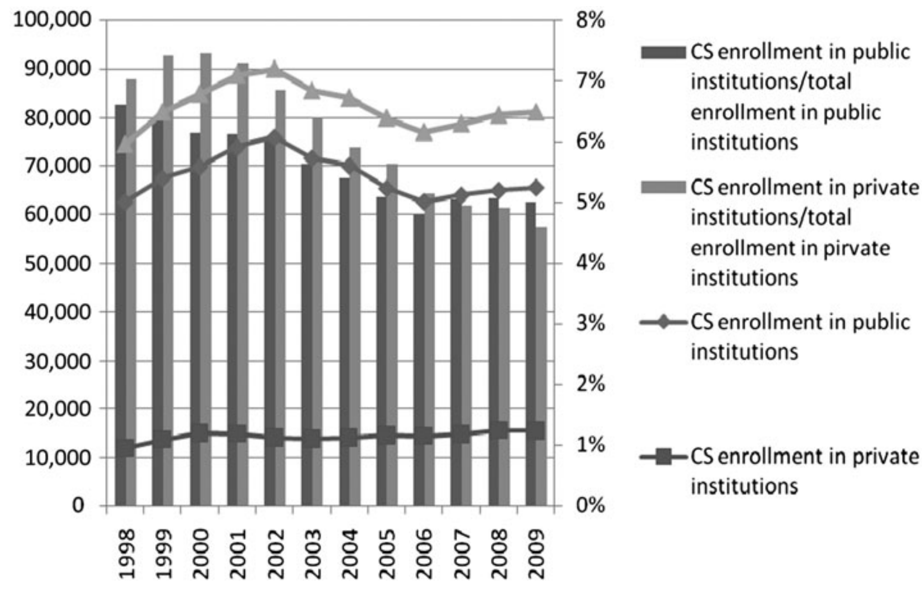

Figure 2. Computer science (CS) enrollments in public and private institutions, 1998–2009
Source: author's elaboration based on SPU yearbooks, 1996–2009.

from 2006 to the end to the series, the change in the slope of the public ratio also meant a change in the rank (SPEI, 2012).

Now, the relative decline of CS should not be attributed to the growth of other fields, but to the stagnation of the absolute enrollment in CS. Indeed, the absolute enrollment in CS stopped growing in the 2000–2010 decade.[5] This is interesting because, as we have pointed out, this is the period when the SIS sector experienced a dramatic upsurge in terms of employment and exports. Why did this happen? How are both trends (the increase in the number of workers and the stagnation of the number of students) related? Before answering these questions, it is necessary to look at the figures for graduates and researchers in order to avoid hasty conclusions. For instance, it could be that stagnant enrollment has been accompanied by an improvement in the ratio of graduation (graduates/students). It would then have been possible for the number of degree holders in CS available to work in software firms to have risen. The next section addresses this issue.

Graduates and degree holders

Current graduation rates

The variables briefly analyzed for students deserve a deeper look when we move on to graduates. Two ratios are interesting, both in the present and in their historical trends: (1) graduates in computer science/enrollment in CS and (2) graduates in CS/total graduates (Table 4).

At 6.4%, the graduation rate of the Argentinean higher education system is extremely low. The average of the Organisation for Economic Co-operation and Development (OECD) is 38.6%, the US 37.8% and Mexico 19.4% (OECD, 2011). Of course, Argentina pays the price for its highly inclusive public education system with this low graduation rate. Nevertheless, the graduation rate of private institutions (12.1%) is also modest, although quite a lot better than that of the public ones (5.34%). Now, the point here is that the graduation rate in CS is even lower than the average of the system. And this is in both public and private institutions. Students tend to drop out of computer science degrees much more than from degrees in other subjects. The same conclusion can be reached from looking at the share of graduates in CS in the overall graduate total. CS graduates accounted for only 3.68% of total graduates, while CS students represented 4.9% of all students enrolled.

Up to this point, the picture is pretty straightforward. Few students choose CS and even fewer complete the degree. Now, what kind of indicator could be used to

Table 4. Graduates in computer science (CS) and related fields and total graduates by type of institution (Argentina, 2009)

Type of institution	Total graduates (2009)/total enrollment (2004)	CS graduates (2009)/CS enrollment (2004)	CS graduates (2009)/total graduates (2009)	CS enrollment (2009)/total enrollment (2009)
Public	5.3%	3.7%	3.7%	5.0%
Private	12.1%	7.3%	3.6%	4.6%
Total	6.4%	4.3%	3.7%	4.9%

Source: author's elaboration based on SPU (2010). The ratio of graduation is calculated from the number of graduates enrolled of five years previously.

decide whether the number of graduates is sufficient to meet the needs of the national system of innovation? We have chosen international comparison. Take the case of the US, the world leader in the software market. Some 63 of the top 100 companies in the world software industry are headquartered in the US (Van Kooten, 2011). Surprisingly, from the standpoint of common sense, their share of the degrees in CS out of the overall total was only 2.4% in 2009 (much lower than the 3.7% in Argentina).[6] It seems that a country can grow and sustain – at least under some special circumstances – a highly innovative software industry without a high ratio of degrees in CS. It could, of course, be argued that the comparison is invalid because it compares two SIS sectors at different stages. It could be that the share of CS graduates in the US was higher at the take-off stage. We will address this possibility in the next section.

This is interesting enough, but let us take another example, the UK. There, the ratio is slightly higher than in Argentina: 3.9%. However, holders of a degree in CS experience the maximum level of unemployment among all higher education graduates in the UK. Indeed, in 2009, the unemployment rate for CS degrees in the UK was 17% and in 2010 it was 14.7% (HESA, 2010). Naturally, this is attributed partly to the shortcomings of formal education in informatics: managers say UK degree holders lack the skills they need; managers do not say they find cheaper skilled labor in India and other countries. So, the example of the UK shows that a higher ratio of degrees in CS does not guarantee that supply meets demand. The lesson is quite simple: graduating a lot of people might be great for the SIS sector, but not necessarily for the workers. The situation in both the US and the UK deserves further investigation. Offshoring, outsourcing, the relationship between market demand and academic supply and especially the relevance of skills acquired through non-formal and informal education must be carefully considered. Nevertheless, a simple conclusion can be drawn: the ratio of degrees obtained in CS (in comparison with other fields) is not necessarily an explanatory variable of the dynamic of the software industry, at least if taken in isolation.

It could be argued that the number of degrees obtained in fields related to informatics (which might be readily converted and become useful for the industry) may be very different in the US and Argentina. Thus, if the bulk of degrees in Argentina were in the social sciences, and in science and engineering in the US, the certified knowledge available for the software industry would be very different in the two economies. A comparison, including the UK, is presented in Figure 3.[7] The argument cannot be sustained for engineering as the three countries have similar shares. It seems partially justified for the sciences. In the US, there are a lot of mathematicians and physicists ready to be absorbed by the SIS sector. Nevertheless, when the UK is added, the argument gets weaker. Indeed, it seems probable that the huge availability of scientists ready to work in the SIS sector helps to explain the unemployment numbers.

But another and yet more interesting objection might be made. Why is the number of graduates in CS related only to total graduates? It could be that CS degree holders were a smaller proportion of total graduates in the US when compared with Argentina, but a higher proportion of the labor market. At the end of the day, what really matters to SIS firms is the availability of skilled human resources in the labor force. A methodological digression must be introduced here. Comparisons of numbers of graduates may be biased because the duration of higher education degrees varies substantively. While a US bachelor degree takes four years to complete,

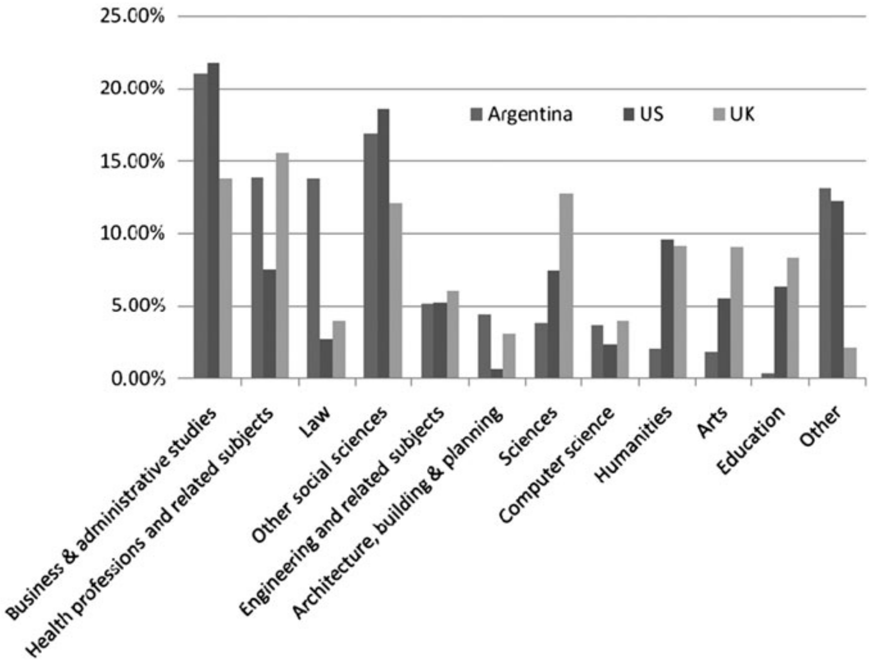

Figure 3. Share of degrees obtained in higher education in various fields (Argentina, US and UK, 2008–2009). The data for Argentina and US are for the 2008/2009 academic year, while the data for the UK are for the 2009/2010 academic year
Sources: author's elaboration based on SPU (2010, Table 1.1.11), NCES (2010, Table 282) and HESA (2010, Table 7).

Argentinean degrees are supposed to take six years. So, we have decided to look at the ratios of years of degree education (multiplying graduates by the expected duration of the standard degrees of the country) out of the total labor force (Figure 4).

The result turns out to be in line with our previous numbers: while Argentina has the lowest total ratio of degree education in the labor force – because of its lower graduation rates – it has a higher ratio in CS than the US. It becomes clear that the figures for graduates in CS (related to labor force or total graduates) are not markedly different in the Argentinean SIS sector from those in the US SIS sector. Indeed, the availability of degree holders in CS in countries like Argentina does not appear to be limiting the development of a powerful SIS sector.

Historical series

As in the case of enrollment, the trend for graduates is counterintuitive. The number of degrees obtained ceased growing when the SIS industry started to grow by leaps and bounds (Figure 5). Numbers of graduates from public institutions grew sharply from 1996 to 2004, but then declined. In any case, it is worth noting that the number of degrees in 2008 was no greater than in 2001. The dramatic expansion of SIS actually took place, fortunately or not, in the complete absence of an expansion of graduates in CS.

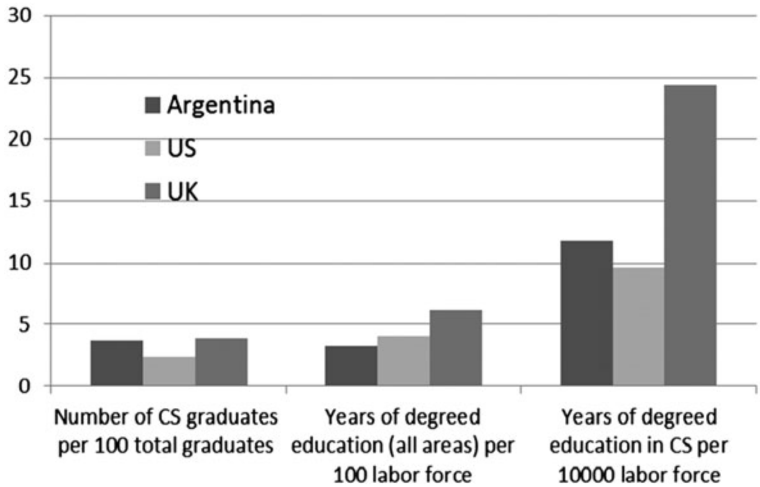

Figure 4. Years of degree education in computer science (CS), total graduates and labor force (Argentina, US, UK, 2008–2009). Years of degree education equal to total graduates multiplied by the standard duration of the respective degrees
Source: author's elaboration based on SPU (2010), NCES (2010), HESA (2010) and World Bank (2014).

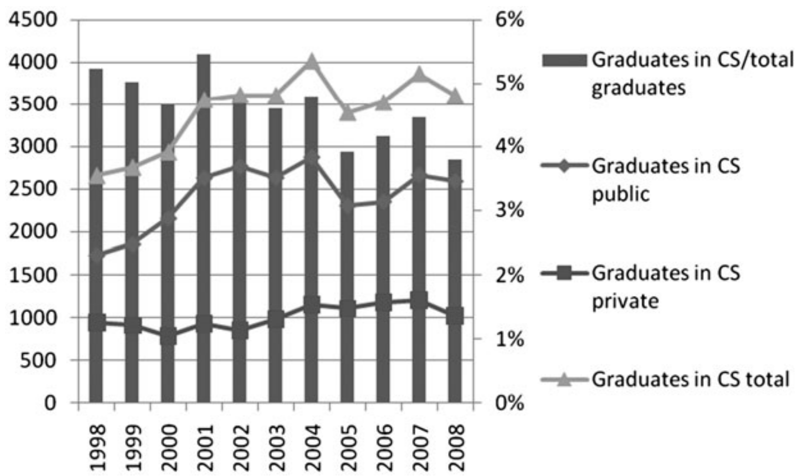

Figure 5. Graduates in computer science (CS) by type of institution, and share of CS graduates of total graduates (Argentina, 1998–2008)
Source: author's elaboration based on SPU (2010).

When we focus on the relative numbers, we find a similar trend: there is nothing akin to an increase in the share of CS degrees in the total degrees. In private institutions, the proportion of degrees in CS vis-à-vis other degrees declines from the start of the series in 1995. On the other hand, in public education, starting from very low ratios, an increase occurs that peaks in 2005 at 4.8%. From then on, the rate decreases.

Now, recalling the international comparisons, it is interesting to discuss the ratio of CS graduates in an historical perspective. From this perspective, it can seem that our point about the mismatch between graduates in CS and the expansion of the SIS sector in the US is unsubstantiated. It is possible, a reader might argue, that the graduates in CS in the US do not represent a huge share of total graduates *today.* But what about the days when SIS was just taking off? Figure 6 provides some data on this point.

The graph shows that the US has never had a huge ratio of CS graduates. It is true that this ratio increased from 1971 to 1985, but it peaked at a modest 4.3%, whilst Argentina's maximum and average are higher. On the other hand, the historical relationship between degree-level knowledge and the labor force is an important indicator (Figure 7). The historical data is hardly surprising. In spite of the limits of the data, it is clear that the number of years of degree education in CS in the labor force is not the key to understanding the difference between these two SIS sectors.

Researchers and postgraduate students

The very top of the pyramid of formal education is composed of two categories: doctoral and postdoctoral students (or research assistants[8]) and PhD holders (full-time researchers). In Argentina, an interesting indicator, despite being only a proxy, is the staff of the National Commission of Scientific and Technological Research (CONICET). This public institution has a staff of some 15,000 full-time researchers and postgraduate scholarship holders, the biggest in the country. From 2003 onwards, the

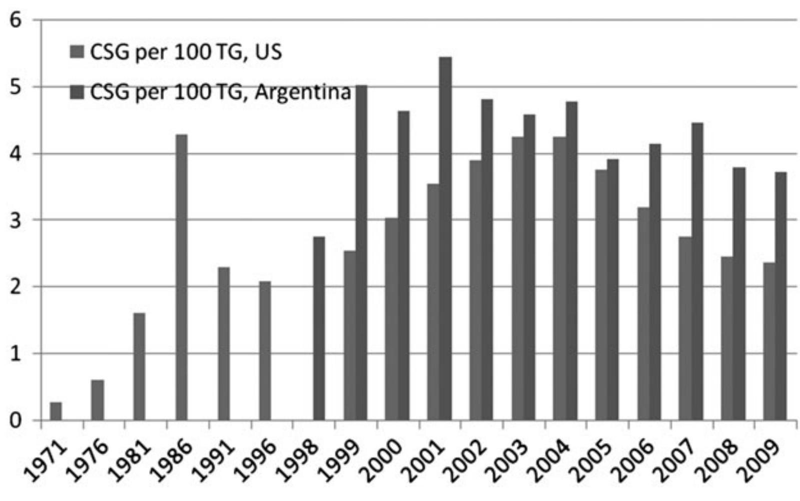

Figure 6. Graduates in computer science (CSG) per 100 total graduates (TG), US and Argentina (1971–2009). Bachelor's degrees conferred by degree-granting institutions, by field of study: selected years, 1970–1971 to 2008–2009
Sources: author's elaboration based on SPU (2010, Table 1.1.11) and NCES (2010, Table 282).

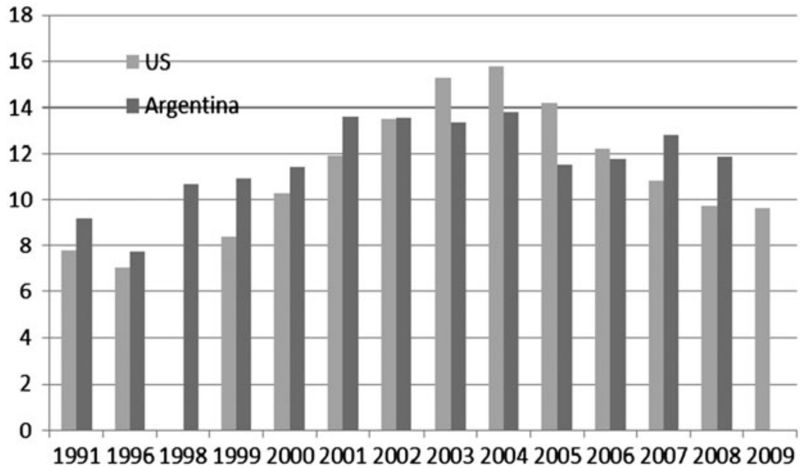

Figure 7. Years of degree education in computer science per 10,000 labor force (Argentina and US, 1991 to 2008–2009). Bachelor's degrees conferred by degree-granting institutions by field of study: selected years, 1991 to 2008–2009. Labor force data is based on World Bank data bank (World Bank, 2014). Years of degree education equal to total graduates multiplied by the standard duration of respective degrees
Source: author's elaboration based on SPU (2010, Table 1.1.11), NCES (2010, Table 282) and World Bank (2014).

institution expanded its personnel dramatically, in the context of an array of national policies focused on fostering science and technology. Of course, graduates and researchers of all fields of knowledge are able to apply for a scholarship or a position in CONICET. So, what happened with computer scientists? Table 5 lists all the sub-fields of knowledge as categorized by CONICET, and the numbers of scholarship holders and researchers.

The numbers are pretty straightforward. CS has the smallest staff, with only 81 scholarship holders and 51 researchers. Why is this? One factor must be mentioned: scholarships and researcher wages are the same in all the sub-fields of knowledge. Thus, an income that is attractive for medical doctors (who abound in Argentina), historians or psychologists is probably not enough for a graduate or PhD holder in CS. Moreover, CONICET is to some extent incompatible with other sources of income. The national (and international) market offers many employment opportunities that pay better than CONICET.

Now, again, it seems useful to make international comparison. Although the task is methodologically challenging, in Figure 8 we attempt to compare shares of researchers by field in Argentina and the US. We find sharp contrasts. The main one is in CS. The ratio of US researchers is seven orders of magnitude bigger than the Argentinean one. But there is also a huge difference in engineering. So, how can we understand these figures? Maybe the ratio of those focused on CS at the apex of formal education is indeed a relevant indicator of the SIS sector. Perhaps some radical innovations, some complex developments, require PhD holders and PhD students. So, while there is little evidence to support managers' complaints of a shortage of graduates, there is more to support arguments that there is a shortage of PhD holders and students.The topic deserves deeper investigation. What kind of SIS companies

Table 5. National Commission of Scientific and Technological Research (CONICET) researchers, and postdoctoral and doctoral scholarships (Argentina, 2010)

Discipline	Doctoral and postdoctoral scholarship holders	Researchers	Total
Biology	1293	855	2148
Medical sciences	668	723	1391
History, anthropology and geography	752	518	1270
Industrial engineering and biotechnology	538	496	1034
Earth sciences	453	471	924
Chemistry	470	408	878
Physics	289	549	838
Biochemistry	446	378	824
Sociology	588	193	781
Philosophy, psychology and educational sciences	496	246	742
Agricultural sciences	415	276	691
Civil, electric and mechanical engineering	266	226	492
Languages, linguistics and literature	264	147	411
Law, political science and international relations	293	111	404
Math	212	166	378
Veterinary sciences	138	107	245
Economics, business and public administration	146	75	221
Habitat	89	91	180
Astronomy	62	114	176
Computer science	81	51	132

Source: CONICET (2014).

in Argentina would hire PhDs? What kind of software products and services cannot be developed locally because of the lack of PhD holders? To what extent are the PhD holders and students employed in the SIS sector involved in radical innovations?

From computer science to software labor market: two explanations for the mismatch

There is a deep mismatch between the software labor market and formal education in CS. Figure 9 summarizes this mismatch. The figure can be split. In the first part, until 2001–2002, the number of workers in the SIS sector had a similar gradient to the number of degrees awarded. However, in the second part of the graph, from 2002 (the year of a huge devaluation) onwards, the number of workers has risen steadily while formal education remained mostly stagnant. How can this be explained? We will now explore two complementary ideas.

Software workers, sectors and wages

So far, we have related workers in the SIS sector to total students and graduates of computer science. However, drawing conclusions from this relationship could be

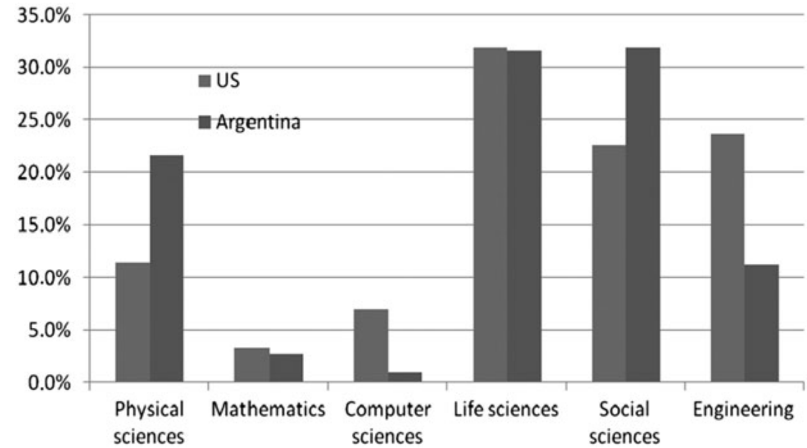

Figure 8. Graduate students and research assistants engaged in full time academic activities, by field as % of total (US, 2008/Argentina, 2009)
Source: author's elaboration based on NSF (2012, Table 5–12) and CONICET (2014).

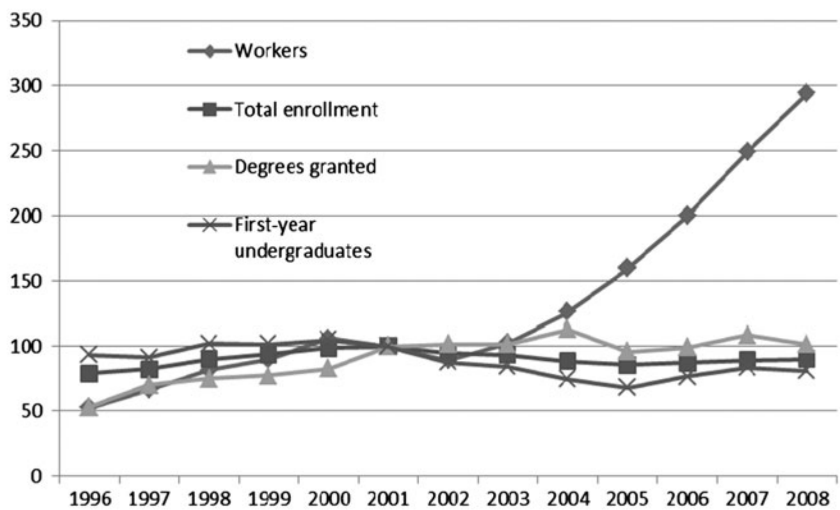

Figure 9. Workers in the SIS sector, computer science students and degrees granted (Argentina, 1996–2008; 2001 = 100)
Source: author's elaboration based on SPU (2010) and OEDE (2012). Only workers registered and in the private sector are considered. Students considered are distinguished between first-year undergraduates (first year, first time) and total enrollment.

problematic if the divergences between branch of activity (sector) and occupation are not taken into account. Indeed, there are software workers (graduates in CS or not) who do not labor in the SIS sector. Does the formal education level of software workers differ across sectors? In order to be legitimate, the cry of the SIS sector for more graduates has to be rooted in the assumption that the sector is hiring more (or at least as many) graduates as the rest of the branches of activity.

Figure 10 shows that only 39% of software workers in the SIS sector have a degree; in other sectors, the rate is never under 60%. On the other hand, only 26% of all graduates working in software occupations are in the SIS sector. Therefore, the alleged lack of CS graduates to meet the needs of the SIS sector is unsubstantiated. The SIS sector hires a limited number of graduates: most go into other sectors. But why? Why are those who succeed in achieving a degree in CS not employed in the expanding SIS sector? An obvious but silent reason is wages. In spite of being absent from Table 6, the evolution of average wages in SIS has been as astonishing as that of employment, but in quite the opposite way.

Not all sectors are included in Table 6. However, even if all the private and registered sectors are considered and disaggregated, SIS is still the last in the ranking of nominal increases in wages. Indeed, it is the only sector where average wages have risen less than inflation. Now, why did the real wages of registered private employment in SIS decrease just when the sector was booming? There are many reasons. Some of them are complex (i.e., the curious situation of higher levels of wages in unregistered companies). Nevertheless, one key point is quite simple: the lack (and in some cases the prohibition) of unionization in the SIS sector (Ferpozzi and Zukerfeld, 2012). Sectors with high wage levels are characterized by specific and powerful unions.

It is not the case that the SIS sector is desperately looking for graduates in CS that the universities are not producing. Instead, the SIS sector is failing to attract many of those graduates, to some extent because of the low wages it is paying. This

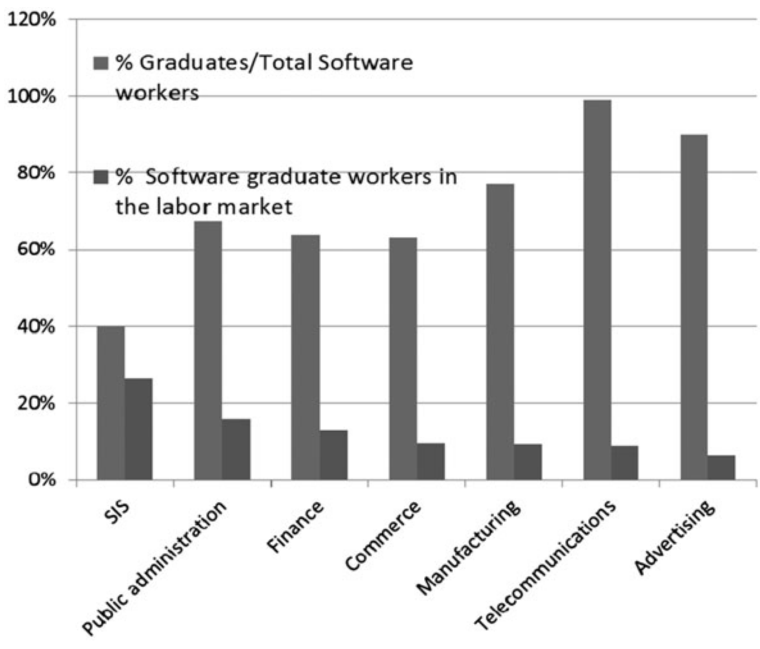

Figure 10. Rates of graduates among software workers in different sectors (Argentina, 2012)
Source: author's elaboration based on SPU (2010) and INDEC (2013).

Table 6. Real wages across sectors (Argentina, 2011/1998)

Sector	Evolution of real wages
Waste recycling and disposal	90%
Transportation	75%
Construction	71%
Health care and social assistance	65%
Agriculture and forestry	62%
Mining, quarrying, and oil and gas extraction	53%
Wholesale trade	46%
Total manufacturing	46%
Legal and accountancy services	45%
Educational services	43%
Software and information services (SIS)	–22%

Source: author's elaboration based on OEDE (2012) for nominal average wages. Inflation is estimated using INDEC (2014) for 1998–2006, and Buenos Aires City (2013) for 2007–2011.

is consistent with international comparisons. The number of graduates in CS in Argentina is not necessarily a problem for the SIS sector; in the US, similar ratios were not an obstacle.

The role of informal and non-formal learning

Evolutionary and neo-Schumpeterian economics have underlined the relevance of skills, tacit knowledge, learning by doing, using, interacting and so on. That is, informal (or non-formal) ways of embodying knowledge have been underscored as key factors in building capabilities. Nevertheless, when it comes to measuring human capital, many researchers tend to rely heavily on statistics of formal education (and research and development – R&D).

> At the level of scholarly research, there is a tendency to expect that the increasing reliance on science and technology in the 'knowledge-based economy' will enhance the role played by formal processes of R&D requiring *personnel with formal S&T qualifications*. And the vast majority of quantitative survey-based studies of innovation simply *have little to say about the relation of DUI (doing*, *using*, *interacting)-mode learning* with innovative performance. (Jensen *et al.*, 2007, p.681, emphasis added).

If the automatic association between formal science and technology (S&T) qualifications and skills acquisition is dubious for the whole economy, it is even more questionable for software production. For instance, the list of founders of the main IT firms is full of dropouts.[9] It is clear that many companies in the SIS sector have been fueled by knowledge which has not been certified by a diploma nor acquired in universities. Within the broad theoretical perspective of evolutionary and neo-Schumpeterian economics, the limits of formal education to fuel the growth of SIS have been specifically highlighted:

> The ability to use knowledge and skills effectively and creatively – i.e. manipulation of words and data, oral and visual representations – for a large proportion of IT [information technology] workers is more important than credentials expressed in terms of education level and field of study. (Borello *et al.*, 2005, p.130)

In our previous research, we investigated this idea through qualitative fieldwork (Dughera *et al.*, 2011). We compared formal, non-formal and informal education as ways of acquiring programming skills, and found that from both the programmers' (graduated or not) and managers' standpoint, the skills acquired through formal education are not central for programming. In other words, the mismatch between CS graduates and SIS growth could be seen in a different light: the sector actually grew, in spite of the alleged lack of degree-qualified workers. Hence, it seems that the expansion of the Argentinean SIS sector in the last decade was based to some extent on different sources of skills from those acquired in education for a degree.

So, where do the skills that programmers actually use come from? Non-formal education, such as private certifications and training courses, is important (López-Bassols, 2002), especially in multinational companies. These companies privatize and globalize knowledge standards, thus challenging the role of the state as the provider of the most legitimate academic credentials. Interviews from our previous qualitative fieldwork led to the conclusion that informal education is the most important from the worker's perspective. Here, with the aid of Table 7, we frame these findings in the theoretical discussion.

Although evolutionary and neo-Schumpeterian economics have contributed in terms of raising questions about informal ways of learning, their emphasis has been limited to cells 2 and 4 of Table 7. Learning in leisure time is not taken into account. Of course, this is not relevant when discussing machinery, industry or biotechnology, but it is a real problem when analyzing informational work (Castells, 1996), creative industries (Mellander, 2009) and, in particular, software production. This is because the learning described in cells 1, 3 and 5 usually starts in childhood. Children start to develop general skills that develop into programming skills outside any form of formal education. Then, as in the case of famous IT dropouts, learning by doing, interacting, etc., was crucial *before* entering the workplace, and outside school. To be sure, this kind of learning continues inside the workplace and colleges, but the roots are in leisure time. In fact, the idea that the boundaries between work time and leisure time are blurring is not at all new (e.g., Lazzaratto, 1996; Rifkin, 2001). It is interesting to note that some public policies have started to focus on building programming capabilities in informal ways.[10] The potential of web-based learning (for programmers and for other informational jobs as well) is overlooked because tacit and codified are traditionally understood to be opposites. Evolutionary and neo-Schumpeterian scholars tend to match tacit knowledge with informal learning, and explicit (or codified) knowledge with formal learning (e.g., Jensen *et al.*, 2007). This approach overlooks web-based ways of learning (such as video-tutorials, forums, communities and so on) that are based on both codified knowledge and informal learning. This kind of learning is the main source of skills for programmers, whether they learn in work time or in leisure time, as teenagers or adults.

Table 7. Informal learning in software workers

Sources	Leisure time	Work time
Learning by doing	1	2
Learning by interacting	3	4
Web-based learning	5	6

Source: adapted from Dughera *et al.*, 2011.

But how does this abstract and theoretical discussion relate to the reality of SIS in Argentina? Moreover, how is it related to what has been said earlier in this paper? We made the point that many CS graduates prefer to work in sectors other than SIS, probably because of the wages. The SIS sector did not appear willing to raise wages in order to attract the graduates it says are missing. This is not because it tries to maximize immediate profits by paying low wages. Had this been its strategy, sector growth would probably have stopped. It seems that SIS has found the energy to grow from other forms of knowledge. Naturally, it could be argued that the sector would have grown much more if it had had more graduates at its disposal, or that the complexity of the products developed by the SIS sector would have been higher if more formal knowledge had been available. This kind of counterfactual hypothesis cannot be tested here, but our international comparisons do not generally support them.

Conclusion

Argentina's SIS sector has been growing steadily in recent decades in terms of sales exports and, particularly, employment. However, stakeholders agree in pointing to the lack of graduates as the main limitation to the development of the sector. This paper covers the arguments. Consequently, a picture of formal education in computer science in Argentina was presented. Not surprisingly, the figures of students, graduates and researchers are low and stagnant. We find a mismatch between the trends in the economic performance of the SIS sector and formal education in CS. The usual response is to demand more formal education and, specifically, more CS graduates. We present three arguments which cast doubt on the wisdom of this response.

First, international comparisons with the US and the UK show that a higher proportion of graduates is not necessarily the main driver of a highly innovative SIS in a thriving national system of innovation. Indeed (although more research is needed), comparison with other countries shows that, even within the realm of formal education, the relative number of degrees in CS is not the only key to growing a powerful SIS sector. Nevertheless, the availability of graduates in related fields, such as engineering and science, could be an important factor in enabling a more complex and innovating SIS sector. Moreover, an idea that deserves in-depth analysis is that the number of PhD students and full-time researchers in CS and related fields could be relevant for distinguishing an SIS sector based on radical innovations from one based on incremental improvements.

Second, the mismatch between formal education in software and the SIS sector could be partly explained by the sector not attracting as many graduates in CS as other sectors. And this is probably a matter of wages: software workers in the Argentinean SIS sector have had little increase in average wages in recent years, and have suffered a loss of purchasing power. In turn, this could be related to the lack (or the direct prohibition) of trade unions in the SIS sector.

Third, the Argentinean SIS sector actually grew, despite the alleged lack of degree-certified workers. Therefore, this expansion seems to be rooted to some extent in different (and complementary) skills from those provided by graduates. Actually, this seems to confirm previous research asserting that, from a programmer's (graduated or not) and manager's standpoint, the skills acquired through formal education are unlikely to be the only relevant ones. Instead, non-formal (training courses and so on) and especially informal learning are valuable sources of knowledge. Informal learning is not limited to learning by doing, interacting and so on in the workplace. It also encompasses – and this is critical for software programmers – learning by every means in leisure time.

This leads us to underscore some theoretical implications that deserve further research in SIS sectors in other countries and in information sectors generally. The main one refers to informal learning. The ways software programmers acquire relevant knowledge confirm some evolutionary and neo-Schumpeterian insights, but go far beyond them. Concepts to understand knowledge acquisition in leisure time are necessary not only to give an account of software skills, but also to grasp those related to music, design, films and other kinds of information work. Likewise, web-based learning cannot be grasped if tacit knowing is associated with informal learning, and codified with formal learning. Nowadays, many skills are learned through codified knowledge in a very informal context. The learning of programmers cannot be unique.

Our analysis of Argentina's SIS leads to conclusions quite different from those of Arora and Gambardella (2004, p.23):

> Most developing regions have abundant labor, but rarely abundant skilled labor. Not only could this hamper the growth of a software industry, such a growth may even increase inequality by greatly increasing demand for the small segment of the population of the highly skilled and educated, and leave virtually untouched the rest. Indeed, the growth of the software industry draws away skilled engineers from other sectors.

In Argentina, the SIS sector did not steal CS graduates from other sectors; it hired thousands of workers without degrees. Thus, the conclusion drawn from an excess supply of engineers (that Arora and Gambardella find in India, Israel and Ireland) is not necessarily the correct one.

We find that it is important to distinguish the requirements of (1) particular sectors, such as the SIS sector, (2) those of the national system of innovation and (3) those of social inclusion. Fortunately, interests may converge to the benefit of all three. Roughly speaking, this was the case with the development of the IT sector in India. However, in other cases, the interests of the sector and the development of social inclusion can diverge. Unfortunately, the literature on SIS and IT sectors tends to overlook these conflicting interests. Thus, in Argentina, it is not at all clear that investing public resources to meet the sector's demand for more graduates in CS would be the best strategy for the national system of innovation, or an efficient means of generating social inclusion. Policy makers of latecomer countries should be aware of this finding, and analyze carefully whether investing in formal education is the best way to foster a SIS sector, especially if the investment is meant to achieve social inclusion.

Finally, policy recommendations must be put into context. In recent years, the Argentinean government has been trying to stimulate the SIS sector by different means. *Plan Argentina 2020* has a special chapter on software production. In the first meeting of the stakeholders, the problem of 'qualified human resources' was the main topic (SPEI, 2012). However, many issues that we have identified as strongly related to this topic were not considered. Nothing was said about the role of informal and non-formal learning. The loss of purchasing power of average wages and the prohibition of unions were not discussed. The fact that computer scientists are the smallest group on CONICET's staff was not mentioned either. And the limitations of the software statistics were not discussed.

We make four recommendations, not only for Argentina, but also for other developing countries:

(1) Non-formal and informal education in computer science must be promoted by the state.
(2) The state must act to encourage unionization and, consequently, increase the wages of the SIS sector, especially if the latter is determined to capture graduates.
(3) It is worth considering whether national agencies of research and development (CONICET in Argentina) should supplement the number of scholarships for PhD students in CS.
(4) Statistics on the SIS sector must be improved and standardized. Representative surveys measuring the whole universe of software productive processes (registered or not, big or small) must be undertaken.

Notes

1. As Jorgenson puts it, 'software is not merely an essential market commodity but, in fact, embodies the economy's production function itself, providing a platform for innovation in all sectors of the economy' (Jorgenson, 2006, p.5).
2. For instance, in 2011 the Strategic Industrial Plan 2020 included software production as a public policy priority (SPEI, 2012).
3. Both the perceived shortage of qualified human resources as the main obstacle and the automatic translation of skilled workforce into CS degree-holders were apparent in the first meeting of the SIS value chain in March 2012 (SPEI, 2012).
4. The numbers in the chart take into account only registered employment (unregistered employment in Argentina is still around 37%) and private employment (non-state, non-governmental organizations, public universities). However, previous work (Zukerfeld, 2011) underlines the relevance of productive processes not measured in these official statistics. So, the employment in software production is probably underestimated here.
5. However, and in spite of being a minor component, private higher education in CS has increased consistently, both in absolute numbers (from 10,257 in 1995 to 15,488 in 2009) and in the share of total computer science students (from 16.7% in 2001 to 19.1% in 2009).
6. An objection can be raised. In the US, some degrees obtained from universities are certified by other sorts of tertiary institutions in Argentina. Typically, this is the case for the disciplines related to education. While in the US they account for 6.4% of total degrees, in Argentina they account for barely 0.4%. The point here – we thank Andrés López for noting this – is that the homogenization of these numbers implies an increase in the relative weight of US degrees in computer science. Nevertheless, the magnitude of the change is marginal and does not alter the point we make.
7. The graph may stimulate discussions that go far beyond the scope of this paper. For instance, the reader will note the huge share of law graduates in Argentina, and might wonder what effect this has on a national system of innovation.
8. Graduate research assistants are full-time graduate students with research assistantships as their main source of income.
9. Bill Gates (Microsoft), Steve Jobs (Apple), Mark Zuckerberg (Facebook), Lawrence Ellison (Oracle), Michael Dell (Dell), Jack Dorsey (Twitter), Matt Mullenweg (WordPress) and Arash Ferdowsi (DropBox) are just a few.
10. For instance, the program Dale Aceptar, which stimulates school childrens' ability to develop videogames (Fundación Sadosky, 2014).

References

Arora, A. and Gambardella, A. (2004) *The Globalization of the Software Industry: Perspectives and Opportunities for Developed and Developing Countries*. Working Paper 10538, National Bureau of Economic Research, Washington DC.

Borello, J., Erbes, A., Robert, V., Roitter, S. and Yoguel, G. (2005) 'Competencias técnicas de los trabajadores informáticos. El caso de la Argentina', *Revista de la CEPAL*, 87, pp.129–46.

Buenos Aires City (2013) *Indice de precios al consumidor*, Congreso de la Nación Argentina, Buenos Aires.

Carmel, E. (2003) 'The new software exporting nations: success factors', *The Electronic Journal of Information Systems in Developing Countries*, 13.

Castells, M. (1996) *The Rise of the Network Society, The Information Age: Economy, Society and Culture*, Vol. 1, Blackwell, Malden MA.

Chudnovsky, D., López, A. and Melitsko, S. (2001) *El sector de software y servicios informáticos (SSI) en la Argentina: situación actual y perspectivas de desarrollo*, Documento de Trabajo, 31, CENIT (Research Centre for Transformation), July.

CONICET (2014) *Conicet en cifras*. Consejo Nacional de Investigaciones Científicas y Tecnológicas, Buenos Aires, available from http://web.conicet.gov.ar/web/conicet.acercade.cifras/cifras

Dughera, L., Yansen, G., Segura, A., Mura, N. and Zukerfeld, M. (2011) 'The techniques of the informatics workers: formal, non-formal and informal education in the production of software', Paper presented at the 9th Globelics International Conference. Buenos Aires, 29 November.

Ferpozzi, H. and Zukerfeld, M. (2012) '¿No más sindicalización en el capitalismo informacional? Un análisis de las herramientas gremiales de los productores de software en Buenos Aires', *Revista Electrónica Gestión de las Personas y Tecnología*, 5, 14, pp.71–86.

Fundación Sadosky (2014) Programa Dale Aceptar, Ministry of Science, Technology and Productive Innovation, available from www.daleaceptar.gob.ar

Gajst, N. (2012) 'La construcción de las políticas públicas dirigidas al sector software y servicios informáticos argentino (2003– 2010)', in *Proceedings of the ACORN-REDECOM Conference*, American Network of Information and Communication (REDECOM) Santiago de Chile, available from http://www.acorn-redecom.org/proceedings2012.html

Ginsberg, M. and Silva Failde, D. (2009) 'Análisis del régimen de promoción de la industria del software y servicios informáticos', Paper presented at AEDA Annual Congress, Buenos Aires, 7 July.

HESA (2010) *Table D - Percent of UK domiciled full-time first degree leavers by subject area(#5) and activity 2009/10 in Destinations of Leavers from Higher Education (DLHE) 2009/10*, Higher Education Statistics Agency, available from http://www.hesa.ac.uk/index.php?option=com_content&task=view&id=2206&Itemid=278 [accessed September 2014].

INDEC (2013) *Encuesta Permanente de Hogares 2012*, Instituto Nacional de Estadísticas y Censos, Argentina, available from http://www.indec.mecon.ar/

INDEC (2014) *Indice de precios al consumidos*, Instituto Nacional de Estadísticas y Censos, available from http://www.indec.mecon.ar/nivel3_default.asp?id_tema_1=3&id_tema_2=5

Jensen, M., Johnson, B., Lorenz, E. and Lundvall, B.-Å. (2007) 'Forms of knowledge and modes of innovation', *Research Policy*, 36, 5, pp.680–93.

Jorgenson, D. (2006) 'Introduction: software and the new economy' in Jorgenson, D. and Wesener, C. (eds) *Measuring and Sustaining the New Economy, Software, Growth, and the Future of the US Economy: Report of a Symposium*, Committee on Measuring and Sustaining the New Economy, National Research Council, Washington DC, pp.31–5.

Lazzarato, M. (1996) 'Immaterial labor' in Virno, P. and Hardt, M. (eds) *Radical Thought in Italy*, University of Minnesota Press, Minneapolis MN, pp.133–47.

López, A., Ramos, D. and Torre, I. (2010) 'Remote work and global sourcing in Argentina' in Messenger, J. and Ghosheh, N. (eds) *Offshoring and Working Conditions in Remote Work*, Palgrave Macmillan, Basingstoke, pp.162–95.

López-Bassols, V. (2002) *ICT Skills and Employment*, Science, Technology and Industry Working Paper 2002/10, OECD, Paris, available from http://dx.doi.org/10.1787/110542373678

Lundvall, B.-Å. and Lorenz, E. (2007) 'Modes of innovation and knowledge taxonomies in the learning economy', Paper presented at the CAS Workshop on Innovation in Firms, Oslo, 30 October.

Malerba, F. and Nelson, R. (2011) 'Learning and catching up in different sectoral systems: evidence from six industries', *Industrial and Corporate Change*, 20, 6, pp.1645–75.
Mellander, C. (2009) 'Creative and knowledge industries: an occupational distribution approach', *Economic Development Quarterly*, 23, 4, pp.294–305.
NCES (2010) *Higher Education General Information Survey 2009*, National Center for Education Statistics, Department of Education, available from http://nces.ed.gov/
NSF (2012) *Science and Engineering Indicators*, National Science Foundation, available at: http://www.nsf.gov/statistics/seind12/
Novick, M., Rojo, S., Castillo, V., Tumini, L. and Breard, G. (2011) 'Nuevas actividades económicas surgidas a partir del paradigma TIC: el sector del software y los servicios de call center' in Novick, M. and Rotondo, S. (eds) *El Desafío de las TIC en Argentina. Crear Capacidades para la Generación de Empleo*, Naciones Unidas, Santiago de Chile, 248–64.
OECD (Organisation for Economic Co-operation and Development) (2011) *Education at a Glance 2011: OECD Indicators, OECD*, Paris, available from http://dx.doi.org/10.1787/eag-2011-en [accessed October 2013].
OEDE (2012) *Boletín Anual de Empleo Registrado y Empresas*, Observatorio de Empleo y Dinámica Empresarial, Ministerio de Trabajo y Seguridad Social, Argentina.
OPSSI (Observatorio Permanente de la Industria de Software y Servicios Informáticos) (2010) *Evolución y perspectivas de las empresas de software y servicios informáticos de la República Argentina*, OPSSI de la CESSI, (Software and Information Services Chamber), June, available from www.cessi.org.ar/opssi/ [accessed October 2013].
OPSSI (Observatorio Permanente de la Industria de Software y Servicios Informáticos) (2013) *Reporte Semestral Sobre el Sector de Software y los Servicios Informáticos de la República Argentina*, OPSSI de la CESSI (Software and Information Services Chamber), available from www.cessi.org.ar/opssi/ [accessed October 2013].
Rifkin, J. (2001) *The Age of Access: The New Culture of Hypercapitalism, Where All of Life Is a Paid-For Experience*, Tarcher Penguin Putnam, New York.
SPEI (Secretaría de planeamiento estratégico industrial) (2012) 'Encuentro de la cadena de valor del software y servicios informáticos', in *Plan Estratégico Industrial 2020*, Ministry of Industry of Argentina, Buenos Aires, available from http://www.industria.gob.ar/wp-content/uploads/2012/12/Informe-Mesa-de-implementaci%C3%B3n-Software-y-SS-Inform%C3%A1ticos.pdf
SPU (2010) *Anuario estadístico 2009*, Secretaría de Políticas Universitarias, Ministerio de Educación de la Nación, available from http://portales.educacion.gov.ar/spu/investigacion-y-estadisticas/anuarios/
UNCTAD (United Nations Conference on Trade and Development) (2012) *The Information Economy 2012: The Software Industry and Developing Countries*, available from http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=271 [accessed October 2013].
Van Kooten, M. (2011) *Global Software Top 100*, available from http://www.softwaretop100.org/global-software-top-100-edition-2011-the-highlights [accessed October 2013].
World Bank (2014) *The World Bank Data Bank*, World Bank, available from http://databank.worldbank.org/data/home.aspx
WTO (2012) *International Trade Statistics 2011*, World Trade Organization, available from http://www.wto.org/english/res_e/statis_e/its2012_e/its12_toc_e.htm
Yoguel, G., Erbes, A. and Robert, V. (2006) 'El sendero evolutivo y potencialidades del sector de software en Argentina' in Yoguel, G., *et al.* (eds) *La Informática en la Argentina, Un Desafío a los Problemas de Especialización y Competitividad*, UNGS-Prometeo, Buenos Aires, pp.155–70.
Zukerfeld, M. (2010) *Capitalismo y Conocimiento: Materialismo Cognitivo, Propiedad Intelectual y Capitalismo Informacional*, Ph.D. thesis, FLASCO (Latin American Institute of Social Sciences), available from www.e-tcs.org [accessed September 2014].
Zukerfeld, M. (2011) 'Una aproximación a la heterogeneidad de los Procesos Productivos de Software en la Argentina', Paper presented at Simposio sobre Sociedad de la Información en las 40 Jornadas Aplicadas de Informática e Investigación Operativa (JAIIO), SADIO (Sociedad Argentina de Informática e Investigación Operativa), Universidad Tecnológica Nacional, Regional Córdoba, 1 September, Córdoba.