CHAIRE INNOVATION

CRÉATION, DÉVELOPPEMENT ET COMMERCIALISATION DE L'INNOVATION

Adoption of digital and advanced technologies in Canada

Catherine Beaudry
Pierre Therrien
Georges Hage
Polytechnique Montreal & ISED

Objectives of the project

- Explore new ways of analyzing survey data
  - Data mining with R
  - Predictive models with association rules
- Study the adoption of business intelligence and smart-manufacturing technology
  - Understand their effect on innovation performance
  - Explore the birth of Industry 4.0 technologies

CHAIRE INNOVATION

Methodology

- Survey of Advanced Technologies (SAT) 2014
  - 7912 firms surveyed on their adoption of advanced technologies
  - 5 families of technologies
    - Manual Handling, **Business Intelligence**, Design, Processing **(smart-manufacturing)**, Green
- Association rules
  - Using R, we calculate the most frequent occurrences of bundles of technologies
  - We predict which technologies will be adopted together

CHAIRE INNOVATION

Defining association rules measures (1/2)

- $Support = \frac{Number\ of\ transactions\ with\ both\ A\ and\ B}{Total\ number\ of\ transactions} = P(A \cap B)$
- {A} => {B} Proportion of firms that have adopted technologies A and B regardless of other technologies adopted.
- For example:
  {A} => {B} with a support of 0.2 means that 20% of all firms in the survey have adopted at least technologies A and B

CHAIRE INNOVATION

Defining association rules measures (1/2)

- Confidence: The probability of occurrence of a rule
- $Confidence = \frac{Number\ of\ transactions\ with\ both\ A\ and\ B}{Total\ number\ of\ transactions\ with\ A} = \frac{P(A \cap B)}{P(A)}$
- {A} => {B} with a confidence of 0.8 means that if a company has adopted technology A, there is a 80% chance that it has also adopted technology B

CHAIRE INNOVATION

Defining association rules measures (2/2)

- Lift: Measure indicating how likely it is to have this rule compared to others. The higher the lift, the better

- $Expected\ Confidence = \frac{Number\ of\ transactions\ with\ B}{Total\ number\ of\ transactions} = P(B)$
- $Lift = \frac{Confidence}{Expected\ Confidence} = \frac{P(A \cap B)}{P(A) \times P(B)}$

CHAIRE INNOVATION

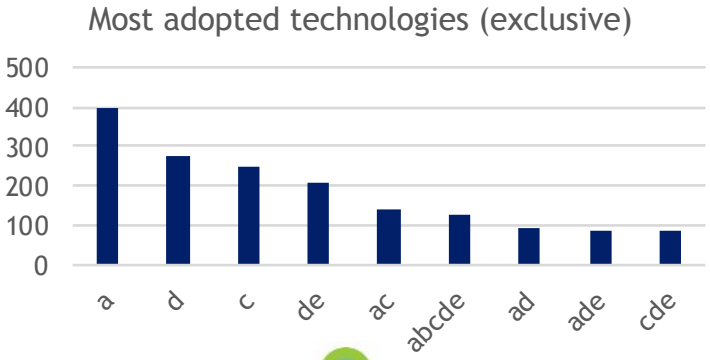
The apriori algorithm, how does it work?

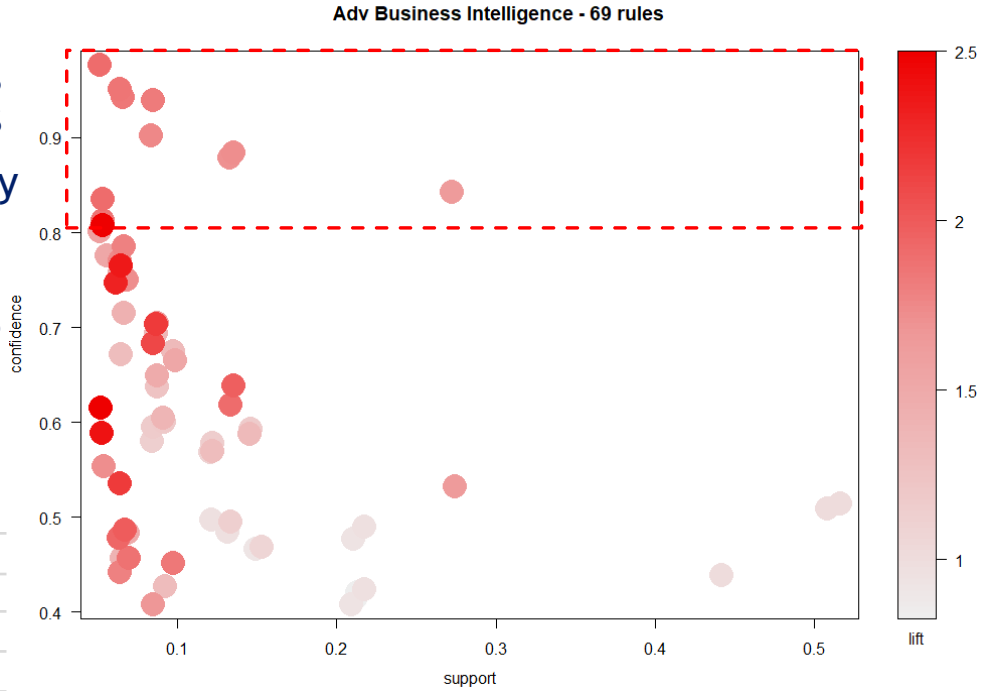
- Data needs to be transformed into transactions (essentially a 0-1 matrix).
- R can then calculate associations rules and predictions
- The chronological order of the rules is important
  - {A} => {B} means that if a firm has adopted A, what is the probability that it also adopted B
  - {B} => {A} means that if a firm has adopted B, what is the probability that it also adopted A

CHAIRE INNOVATION

Advanced Business Intelligence technologies

- Single adoption of technology is the most popular amongst firms
- Firms also adopt complementary technologies such as de and ac
- About 120 firms adopt all technologies – we expect to see larger firms in that category





a. Executive dashboards
b. Big Data Software
c. Live-stream monitoring
d. SaaS and cloud computing software
e. IaaS and cloud computing hardware

- When we filter with C>0,4 we obtain 69 rules
- We set the threshold to C>0.8 to study the most interesting rules

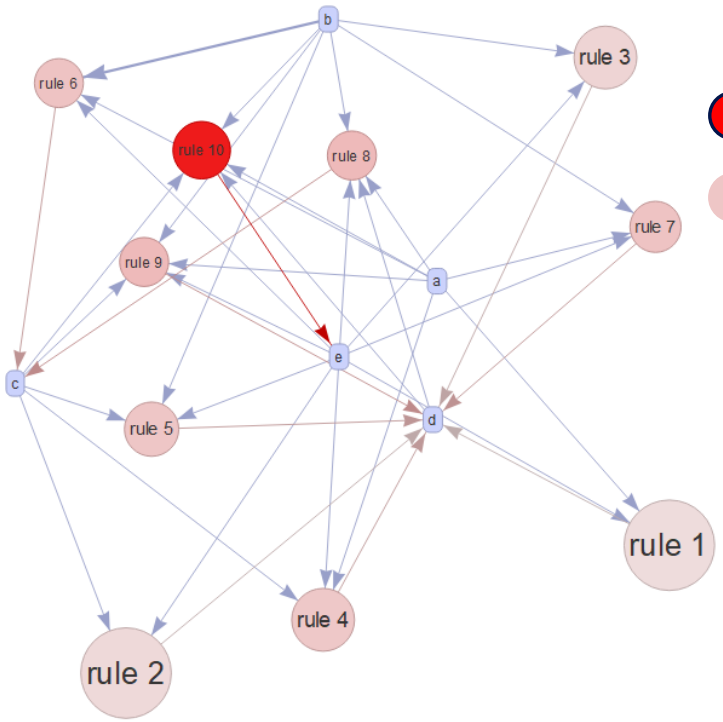
CHAIRE INNOVATION

Advanced Business Intelligence technologies

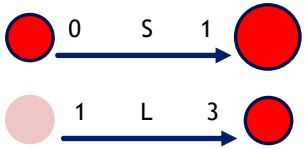
- Technologies c d e are a very popular choice as more than 13% of firms have adopted them together
- Rule 6 almost has a 100% confidence rate
- Rule 10 is similar to rule 6 and is more likely to happen because it has the higher lift

Rules	Description	S	C	L
2	ce => d	0.135	0.89	1.72
6	abce => d	0.053	0.98	1.90
10	abcd => e	0.053	0.81	2.49

Estimated Rules Network C>0.8

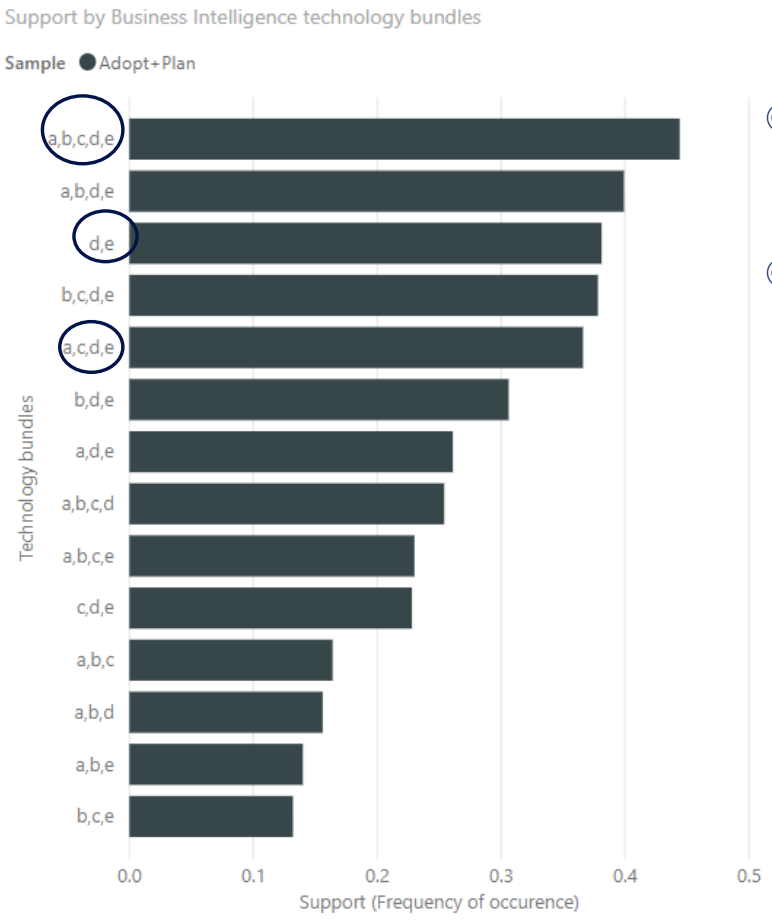


a. Executive dashboards
b. Big Data Software
c. Live-stream monitoring
d. SaaS and cloud computing software
e. IaaS and cloud computing hardware



CHAIRE INNOVATION

Business Intelligence technology adoption patterns are stable with time

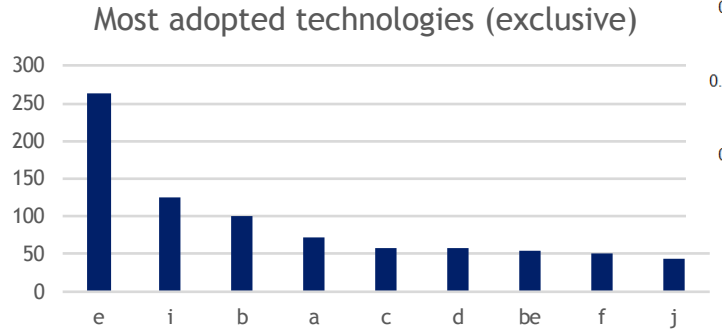


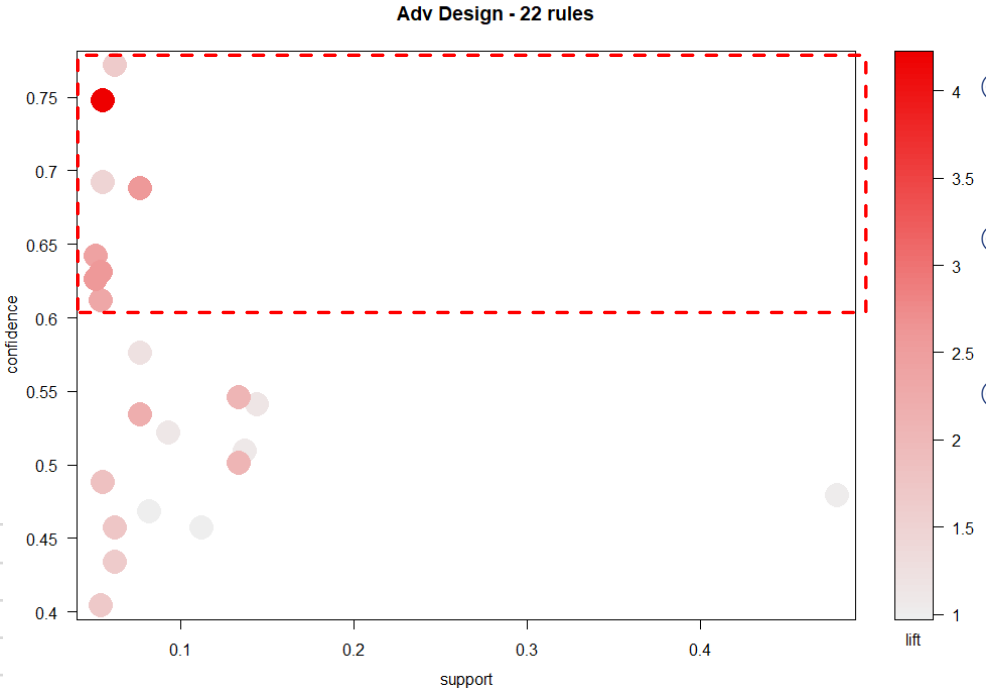
- The **Adopt Only** sample represents firms that have adopted in prior to 2014
- The **Plan Only** sample takes a snapshot at firms that were planning to adopt in 2014-2016
- The top 3 bundles Graph 1 are still in the top 5 in Graph 2, suggesting this family of technologies is mature

a. Executive dashboards for data analytics and decision making
b. Software for large scale data processing
c. Live-stream processing technology or real-time monitoring
d. SaaS and cloud computing software
e. IaaS and cloud computing hardware

Advanced Processing and Fabrication technologies

- Firms prefer to adopt single technologies in this category with computer machinery being the most popular
- Only 1520 firms adopted these technologies which is one of the lowest amongst all families





- When we filter with C>0,4 we obtain 22 rules
- The graph shows us that there are no rule at C>0.8
- In this case, we choose to use C>0.6 to get a bigger pool of rules

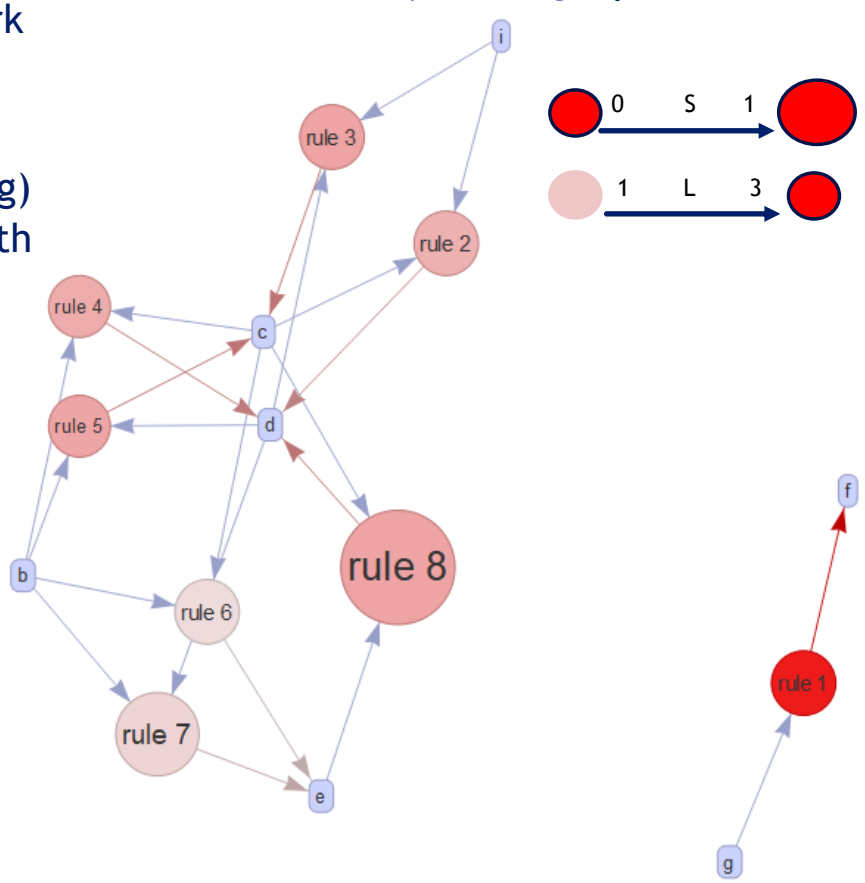
a. Flexible Manufacturing Cells or Systems
b. Lasers used in material processing
c. Robots with sensing or vision systems
d. Robots without sensing or vision systems
e. 4-9 axis computer numerically controlled machinery
f. Additive manufacturing/3D printing for plastics
g. Additive manufacturing/3D printing for metals
h. Additive manufacturing/3D printing for other than plastics or metals
i. Automated machinery for sorting, transporting or assembling parts
j. Plasma sputtering
k. Micro-manufacturing
l. MEMS

CHAIRE INNOVATION

Advanced Processing and Fabrication technologies

- Technologies f g are completely isolated from the rest of the network and rule 1 has the higher lift with 4.21.
- Technology d (robots without sensing) is the most used in this network, with 5 rules

Estimated Rules Network C>0.6

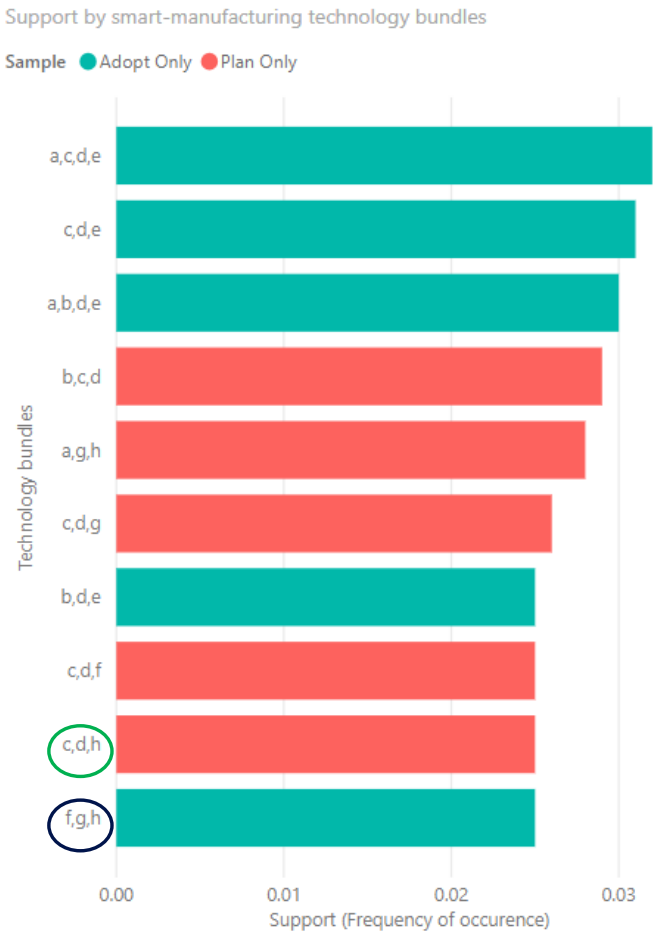


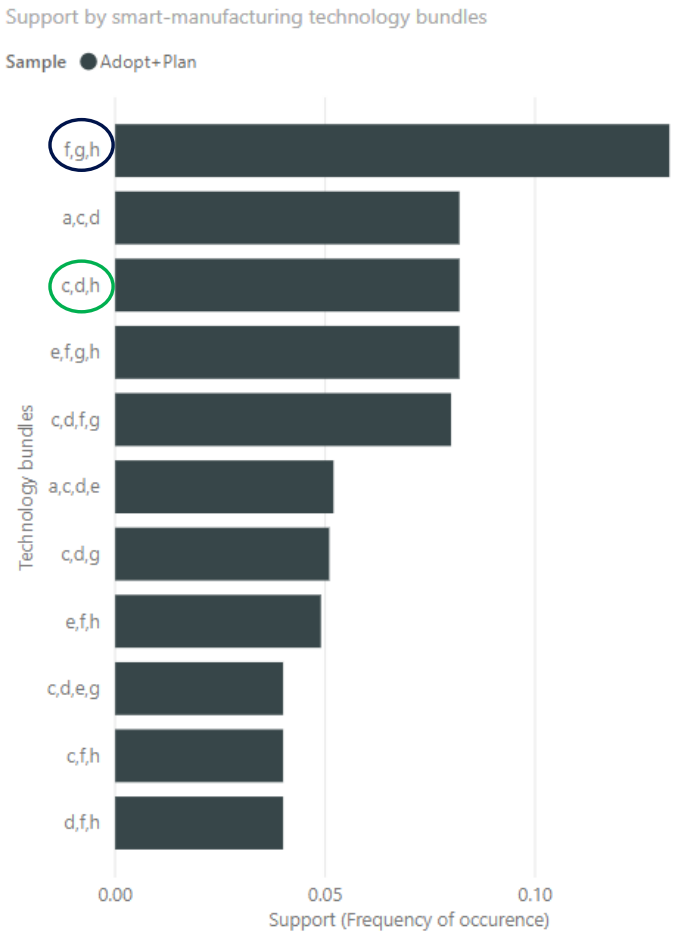
a. Flexible Manufacturing Cells or Systems
b. Lasers used in material processing
c. Robots with sensing or vision systems
d. Robots without sensing or vision systems
e. 4-9 axis computer numerically controlled machinery
f. Additive manufacturing/3D printing for plastics
g. Additive manufacturing/3D printing for metals
h. Additive manufacturing/3D printing for other than plastics or metals
i. Automated machinery for sorting, transporting or assembling parts
j. Plasma sputtering
k. Micro-manufacturing
l. MEMS

Rules	Description	S	C	L
8	ce => d	0.077	0.69	2.58
7	bd => e	0.062	0.77	1.61
1	g => f	0.055	0.75	4.21

CHAIRE INNOVATION

Smart-manufacturing technology adoption patterns are completely changing with time.





- The **Adopt Only** sample represents firms that have adopted in 2014 or before
- The **Plan Only** sample takes a snapshot at firms that were planning to adopt in 2016 or later
- Technologies f,g,h (3D printing are present in the Graph 1 but mostly in the Plan Only Sample
- These technologies are in top bundles in Graph 2, suggesting that 2014 was the birth of Industry of 4.0 and 3D printing

a. Flexible Manufacturing Cells or Systems
b. Lasers used in material processing
c. Robots with sensing or vision systems
d. Robots without sensing or vision systems
e. 4-9 axis computer numerically controlled machinery
f. Additive manufacturing/3D printing for plastics
g. Additive manufacturing/3D printing for metals
h. Additive manufacturing/3D printing for other than plastics or metals
i. Automated machinery for sorting, transporting or assembling parts
j. Plasma sputtering
k. Micro-manufacturing
l. MEMS

IV probit to measure the impact on business intelligence technologies on innovation performance

	allinno	prodinno	procinno	markinno	orginno
lnIndexQ8 (Probit)	2.508****	1.514****	2.383****	1.880****	2.459****
Bus Strat-Q64a	0.285*	0.329***	0.168	0.042	0.143
Bus Strat-Q64b	0.308**	0.402****	0.054	0.112	0.151
Q67ab	0.303*	0.118	0.061	-0.046	0.03
Collab-Q67c	-0.015	0.184*	0.035	0.002	0.021
Bus Strat-Q68a	-0.072	0.133	0.124	-0.044	0
Bus Strat-Q68b	-0.161	-0.223	-0.098	-0.138	-0.179
Bus Strat-Q68c	0.237	0.278**	0.069	0.117	0.185
Q68de	0.346***	0.235**	0.180**	0.189**	0.152*
lnCtrl_size	0.002	-0.013	0.023	-0.053*	0.009
lnCtrl_age	-0.008	-0.062	0.03	-0.029	-0.022
inress	0.169	0.092	0.310***	0.288**	0.188*
inlab	0.496***	0.606****	0.482****	0.415***	0.473****
inscal	-0.033	0.188	0.164	0.14	0.008
inspec	0.456**	0.271*	0.264*	0.135	0.289**
insci	0.26	0.551***	-0.006	0.088	-0.042

lnIndexQ8 (OLS)					
Q67ab	0.054*	0.054*	0.054*	0.054*	0.053*
Collab-Q67c	0.03	0.03	0.029	0.03	0.028
lnCtrl_size	0.002	0.002	0.003	0.002	0.003
lnCtrl_age	-0.012	-0.012	-0.012	-0.012	-0.012
inress	-0.055*	-0.056*	-0.056*	-0.055*	-0.056*
inlab	-0.098**	-0.097**	-0.098**	-0.098**	-0.100**
inscal	0	0	0	0	-0.001
inspec	-0.062	-0.062	-0.061	-0.062	-0.062
Insci	0	0	0.001	0	0
lnIndexQ13	0.078***	0.081***	0.099****	0.076***	0.116****
CAPEX_Q31b	0.029****	0.030****	0.028****	0.029****	0.025****
Q34 - Empl Recruit	0.082****	0.074***	0.072****	0.082****	0.071****
constant	0.929****	0.925****	0.910****	0.931****	0.900****
N	1030	1030	1030	1030	1030
p_exog	0	0.009	0	0	0
OVERID	0.193	0.185	0.787	0.051	0.069

* p<0.1, ** p<0.05, *** p<0.01, **** p<0.001

CHAIRE INNOVATION

IV probit to measure impact of smart-manufacturing adoption on innovation performance

	allinno	prodinno	procinno	markinno	orginno
lnIndexQ16 (Probit)	1.714****	0.833**	1.408****	0.929***	1.418****
Bus Strat-Q64a	0.026	0.137	-0.067	-0.117	-0.134
Bus Strat-Q64b	-0.011	0.277**	-0.085	-0.055	-0.065
Q67ab	0.048	-0.072	-0.036	-0.129	-0.05
Collab-Q67c	-0.08	0.117	0	0	0.007
Bus Strat-Q68a	-0.122	0.241*	0.029	0.164	0.063
Bus Strat-Q68b	0.198	-0.086	0.267*	0.147	-0.002
Bus Strat-Q68c	0.268	0.252*	0.1	0.204	0.09
Q68de	0.031	0.069	0.004	0.059	0.019
lnCtrl_size	-0.116****	-0.064	-0.082**	-0.091***	-0.077**
lnCtrl_age	0.012	-0.032	0.041	0.009	-0.001
inress	-0.270**	-0.254**	-0.075	0.052	-0.185*
inlab	-0.458**	-0.167	-0.380**	-0.161	-0.535****
inscal	-0.508****	-0.126	-0.187	0.086	-0.274**
inspec	-0.431**	-0.078	-0.320**	-0.26	-0.420***
insci	-0.231	0.195	-0.503***	-0.316*	-0.435***
constant	0.591**	0.156	0.097	-0.026	0.172

lnIndexQ16 (OLS)					
Bus Strat-Q64a	0.208****	0.212****	0.210****	0.210****	0.210****
Bus Strat-Q64b	0.116***	0.115***	0.115***	0.116***	0.116***
Q67ab	0.107**	0.100**	0.102**	0.104**	0.103**
Collab-Q67c	0.051	0.05	0.051	0.051	0.051
lnCtrl_size	0.064****	0.066****	0.065****	0.065****	0.064****
lnCtrl_age	-0.006	-0.005	-0.006	-0.005	-0.006
inress	0.136**	0.133**	0.131**	0.137**	0.132**
inlab	0.422****	0.424****	0.422****	0.424****	0.422****
inscal	0.219****	0.219****	0.220****	0.217****	0.220****
inspec	0.275****	0.275****	0.273****	0.277****	0.273****
insci	0.264****	0.266****	0.267****	0.263****	0.267****
lnIndexQ21	0.076	0.127***	0.125***	0.087*	0.116***
CAPEX_Q31c	0.020**	0.008	0.020**	0.009	0.022***
Q34 - Empl Recruit	0.129****	0.133****	0.107***	0.150****	0.103***
N	949	949	949	949	949
p_exog	0	0.112	0	0.016	0
OVERID	0.056	0.619	0.109	0.406	0.106

* p<0.1, ** p<0.05, *** p<0.01, **** p<0.001

CHAIRE INNOVATION

Conclusion and future research

- Adoption can be a complex process because it is “à la carte”
- SAT 2014 gives an insight into the birth of Industry 4.0 technologies
- A more accessible data could allow better analysis and the use of new methodologies
- A new SAT would allow to confirm what bundles of technologies firms are adopting 5 years later
- The results have key policy implications and superclusters could be the key to facilitate the adoption of these technologies

CHAIRE INNOVATION

Thank you

Questions? Suggestions?

CHAIRE INNOVATION