CHAIRE INNOVATION

CRÉATION, DÉVELOPPEMENT ET COMMERCIALISATION DE L'INNOVATION

Adoption of digital and advanced technologies in Canada

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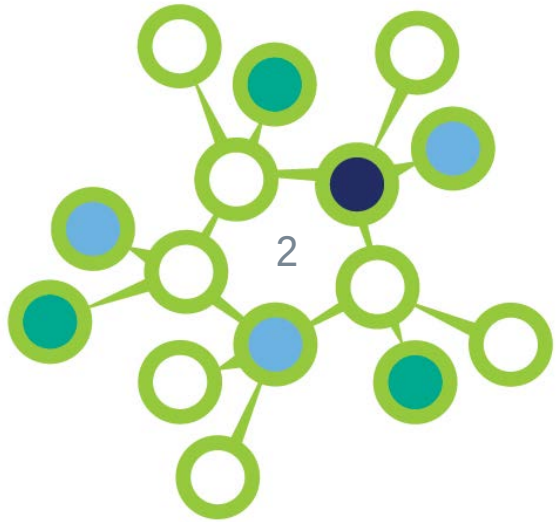
Objectives of the project

- Explore new ways of analyzing survey data
  - Data mining with R
  - Predictive models with association rules

- Understand the effect of advanced technology adoption – often ICT-driven
  - On innovation performance
  - Portrait of firms adopting certain types of technologies



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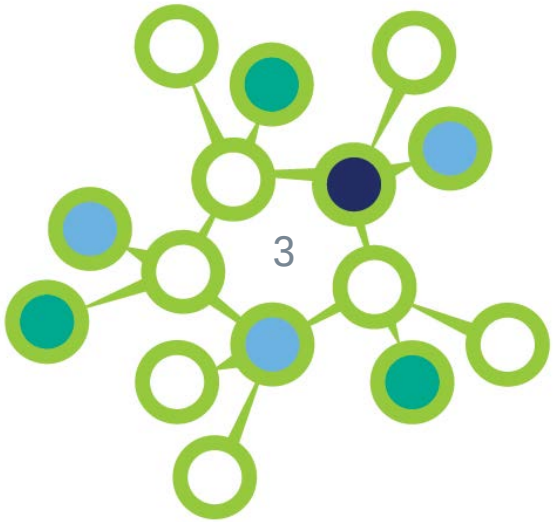
Methodology

- Survey of Advanced Technologies (SAT) 2014
  - 7912 firms surveyed on their adoption of advanced technologies
  - 5 main families of technologies
    - Material Handling, Business Intelligence, Advanced Processing, Advanced Design, Green technologies
- Association rules
  - Using R and the *apriori algorithm*, we calculate the most frequent occurrences of certain groups of technologies
  - We predict which technologies will be adopted based on three measures: **support**, **confidence** and **lift**



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Defining association rules measures

- $Support(S) = \frac{Number\ of\ firms\ adopting\ both\ A\ and\ B}{Total\ number\ of\ firms} = P(A \cap B)$
- {A} => {B} Proportion of firms that have adopted technologies A and B regardless of other technologies adopted. This number is between 0 and 1
- In this case, A is what we call the antecedent and B is what we call the consequent
- 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

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Defining association rules measures

- $Confidence(C) = \frac{Number\ of\ firms\ with\ both\ A\ and\ B}{Total\ number\ of\ firms\ with\ A} = \frac{P(A \cap B)}{P(A)}$
- {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
- The confidence measures the probability of a technology to be adopted so it ranges from 0 to 1 (or 0 to 100%)

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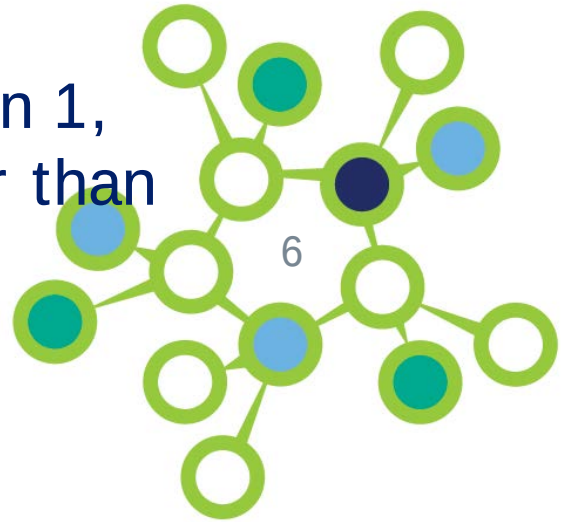
Defining association rules measures

- $Expected\ Confidence = \frac{Number\ of\ firms\ with\ B}{Total\ number\ of firms} = P(B)$
- $Lift(L) = \frac{Confidence}{Expected\ Confidence} = \frac{P(A \cap B)}{P(A) \times P(B)}$
- The lift measures the interestingness of a rule
- Typically the lift can range from 0 to infinity but in practice, the lower and upper lift will vary from one rule to another
- In theory, we're looking for rules that have a lift greater than 1, which would mean that the confidence of this rule is greater than what's expected



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The *apriori* algorithm - how does it work?

- Once we submit to R a CSV file of all the firms adoption choices, the *apriori* algorithm will compute and try to find association rules based on confidence and support thresholds
- The chronological order of the rules is important
  - {A} => {B} means that if a firm has adopted A first, what is the probability of adopting B
  - {B} => {A} means that if a firm has adopted B first, what is the probability of adopting B
- This distinction wasn't available in the survey but in reality, this difference makes sense

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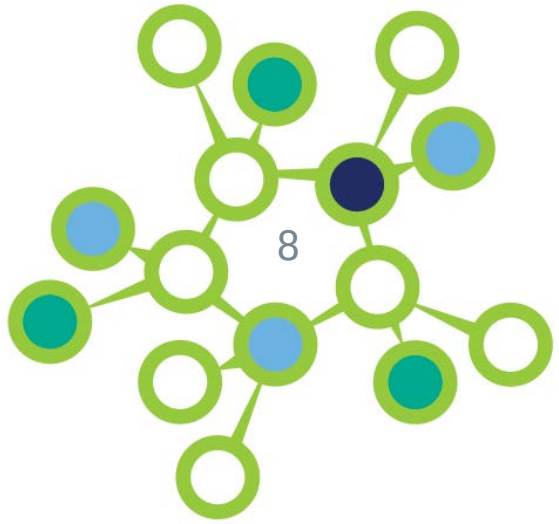
Results of the *apriori* algorithm

By family of advanced technologies



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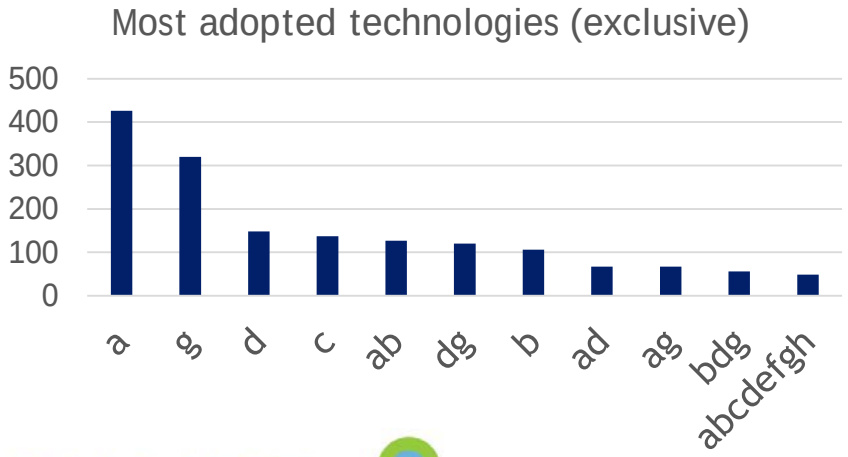
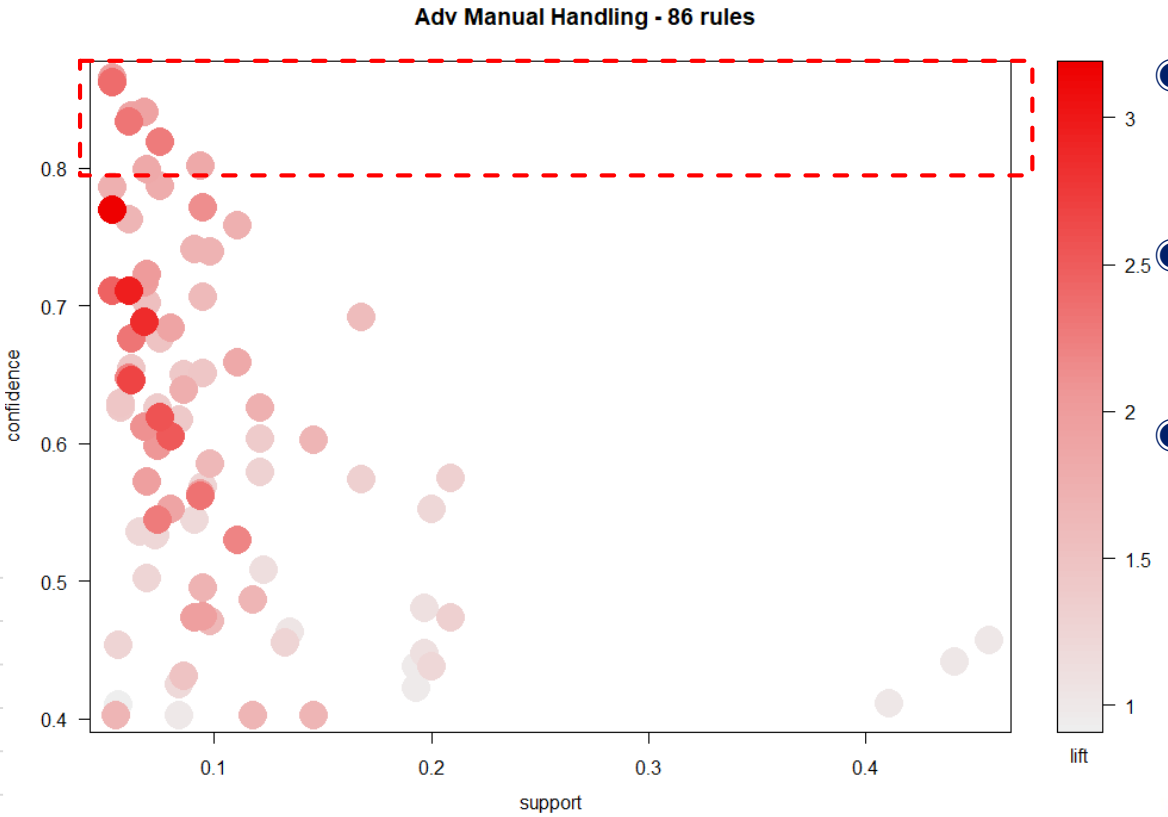
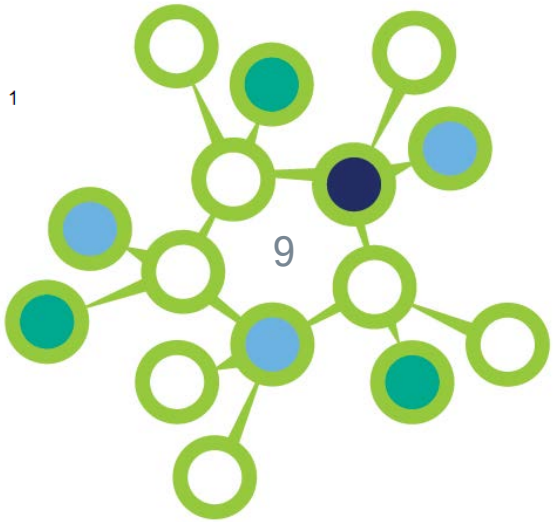
Advanced Material Handling, Supply Chain and Logistics technologies

- Firms prefer to adopt single technologies in this category: CRM software and Software for demand forecasting are the most popular
- At least 40 firms have adopted all technologies in this category





- When we filter with C>0,4 we obtain 86 rules
- The graph shows us that they are less rules if we use C>0.8
- We decided to use C->0.8 for our network analysis



a. CRM software
b. Software for demand forecasting
c. Transportation management system
d. Warehouse Management System
e. Supply chain collaboration
f. Automated Storage and Retrieval System
g. Automated bar/QR coding
h. RFID

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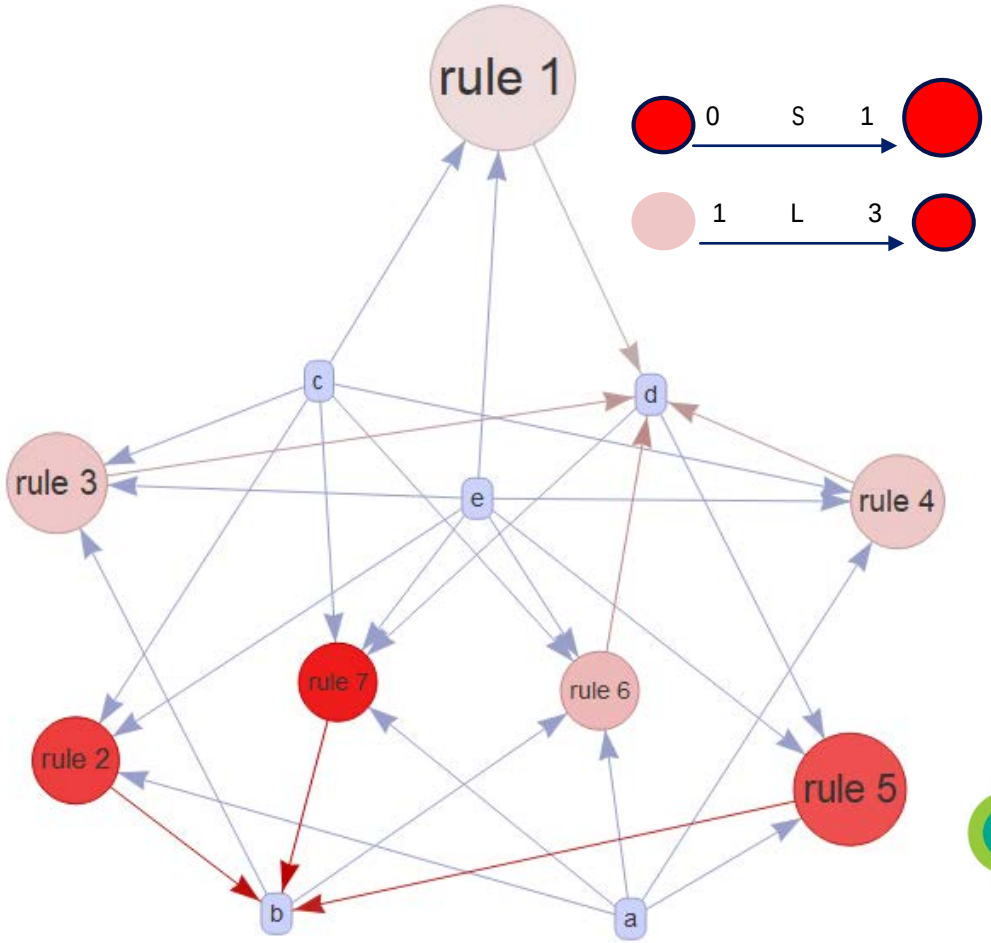
Advanced Material Handling, Supply Chain and Logistics technologies

- Rules can be selected by support, confidence or lift. Lift must be greater than one for a rule to be valid
- Rules 6 and 7 are similar in terms of support and confidence, but we prefer rule 7 because the lift is higher

Rules	Description	S	C	L
1	ce => d	0.094	0.80	1.82
6	abce => d	0.053	0.87	1.96
7	acde => b	0.053	0.86	2.38

Estimated Rules Network C>0.8



a. CRM software
b. Software for demand forecasting
c. Transportation management system
d. Warehouse Management System
e. Supply chain collaboration
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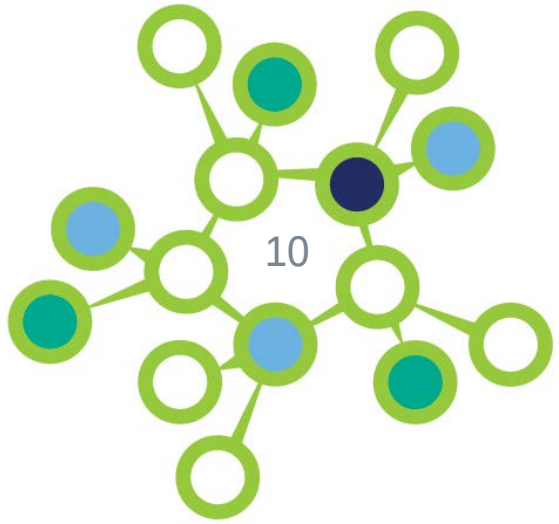
Q1_Network_v2.html



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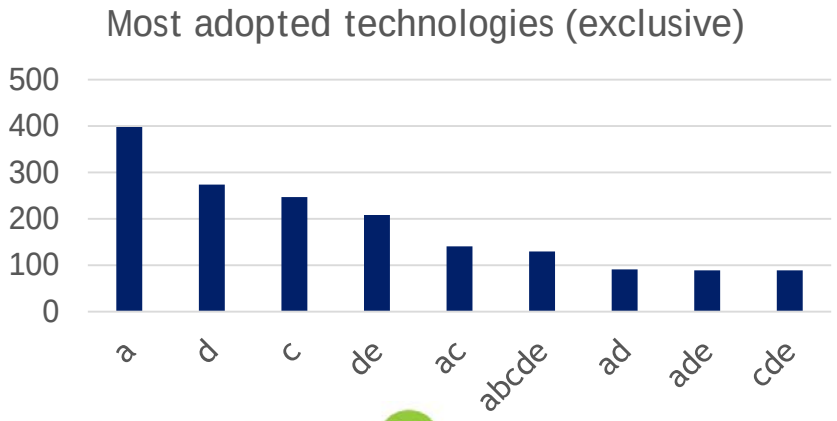
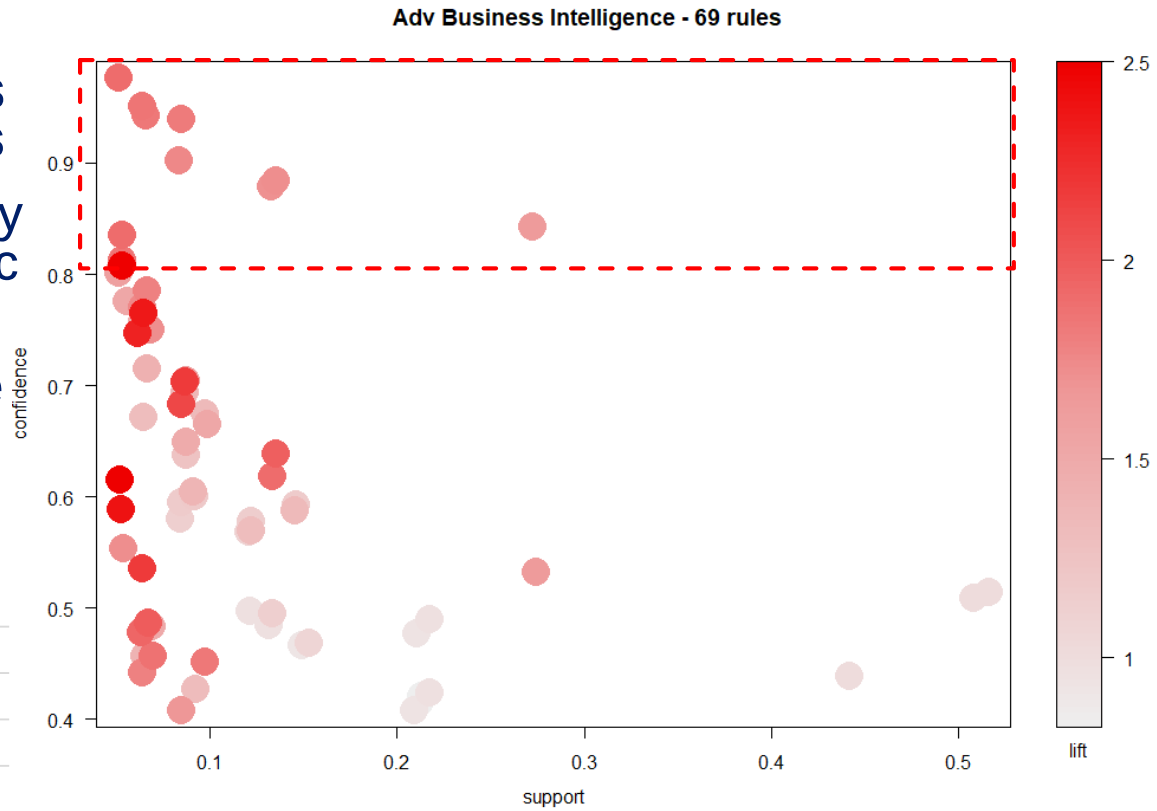
Advanced Business Intelligence technologies

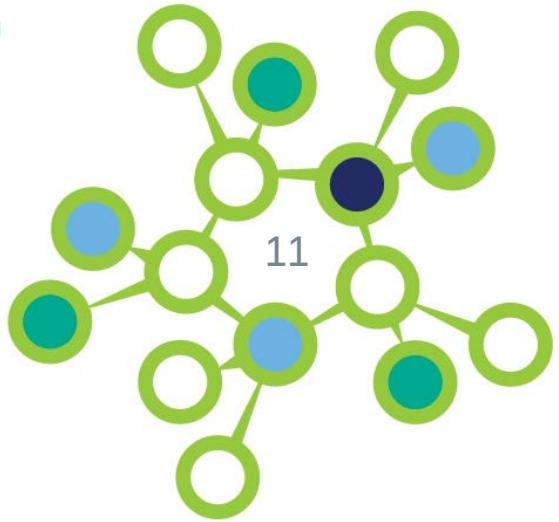
- Single adoption of technology is the most popular amongst firms
- Firms also adopt complementary technologies such as d,e and a,c
- About 120 firms adopt all technologies – we expect to see larger firms in this category





a. Executive dashboards for data analytics and decision making
b. Software for large scale data processing (e.g. Hadoop)
c. Live-stream processing technology or real-time monitoring
d. Software as a service (AaaS) and cloud computing software
e. Infrastructure as a service (IaaS) and cloud computing hardware

- When we filter with C>0,4 we obtain 86 rules
- The graph shows us that they are less rules if we use C>0.8
- We decided to use C>0.8 for our network analysis



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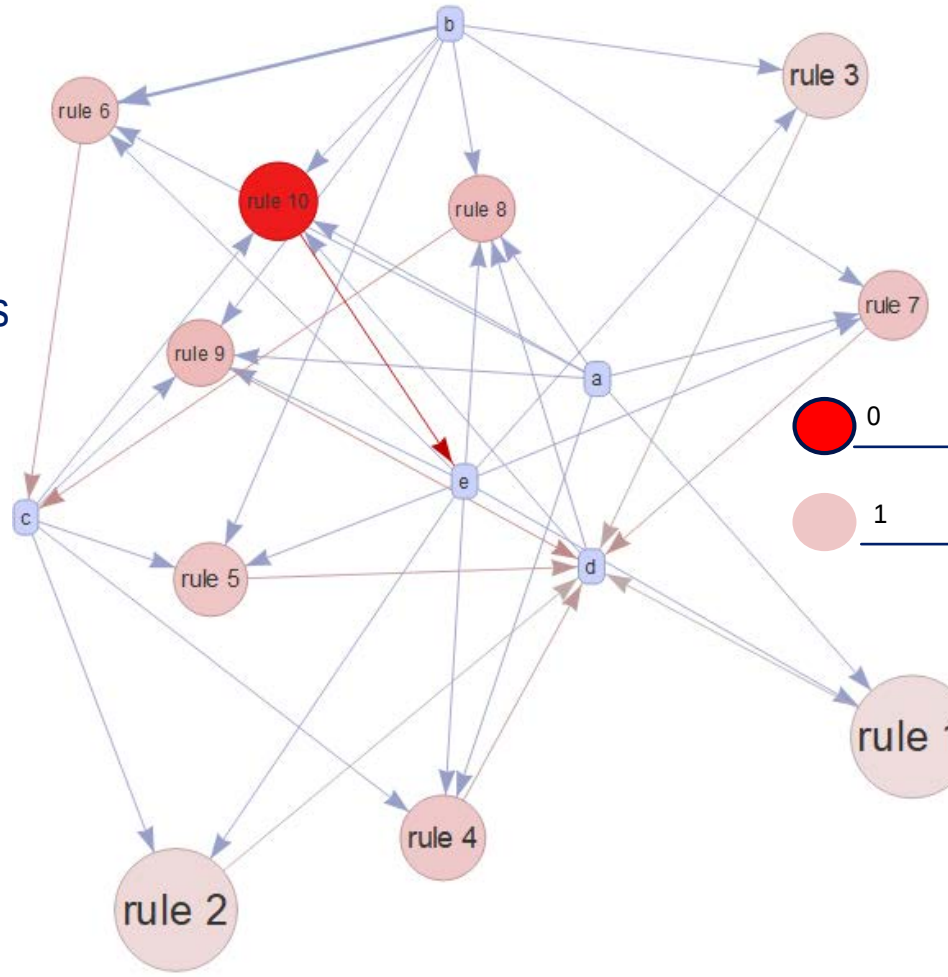
Advanced Business Intelligence technologies

- 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

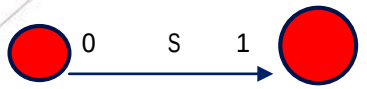
Rules	Description	S	C	L
2	ce => d	0.135	0.89	1.72
6	abce => d	0.053	0.98	1.90
10	abcd => e	0.053	0.81	2.49

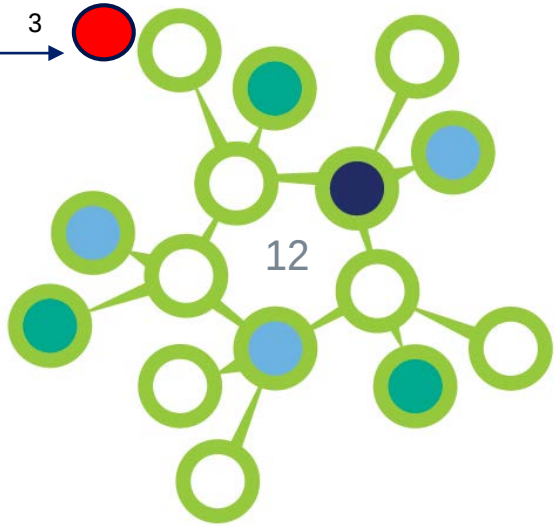
Estimated Rules Network C>0.8



a. Executive dashboards for data analytics and decision making
b. Software for large scale data processing (e.g. Hadoop)
c. Live-stream processing technology or real-time monitoring
d. Software as a service (AaaS) and cloud computing software
e. Infrastructure as a service (IaaS) and cloud computing hardware

Q2_Network_v2.html





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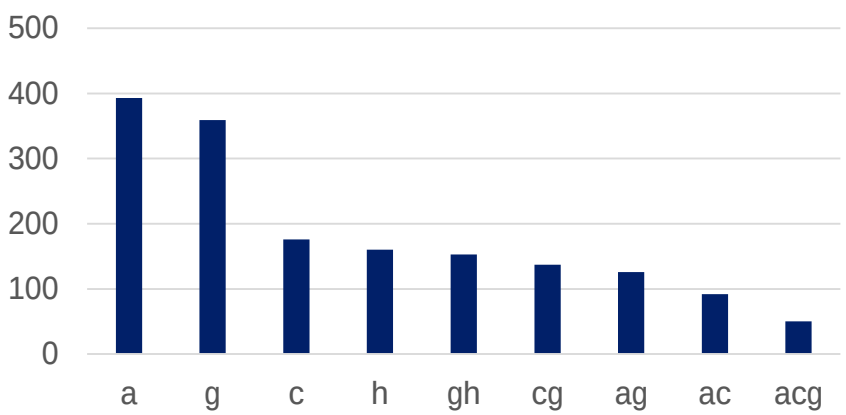
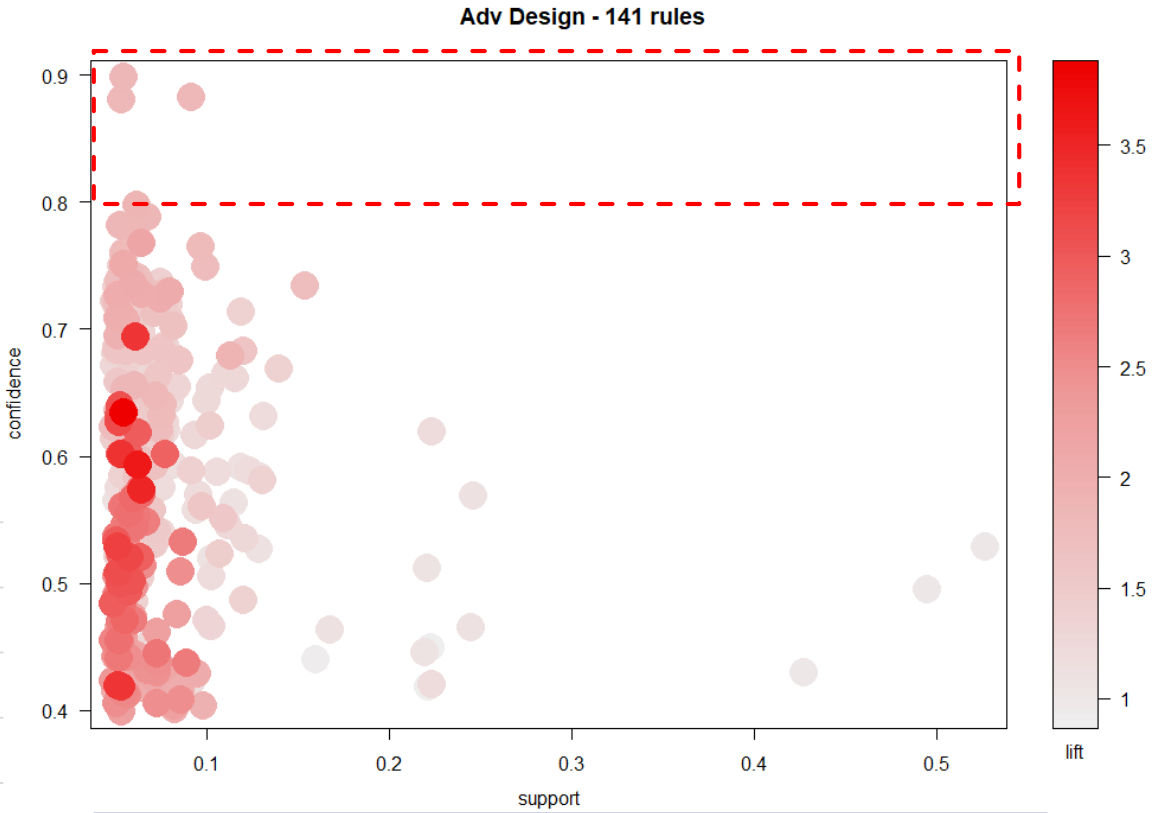
Advanced Design and Information Control Technologies

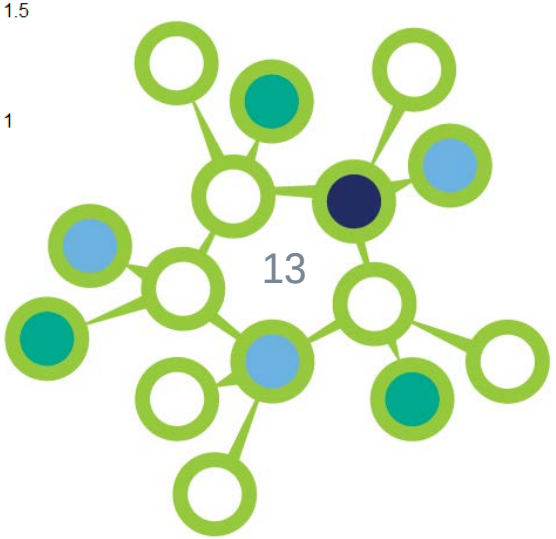
- Firms prefer to adopt single technologies in this category
- Technology g is the most popular to combine with. Extranet is often used with other technologies





a. CAE, CAM, Virtual Product development
b. Virtual manufacturing
c. Enterprise Resource Planning (ERP)
d. Manufacturing Execution System
e. Software Integration of quality results
f. Manufacturing Resource Planning
g. Extranet and EDI
h. Wireless communications for production
i. Sensor network and integration
j. Computer integrated manufacturing
k. Automated systems for inspection
l. Unmanned aerial system (drone)

- When we filter with C>0,4 we obtain 141 rules
- The graph shows us that there are only 3 rules C>0.8
- In this case, we choose to use C>0.765 to get a bigger pool of rules



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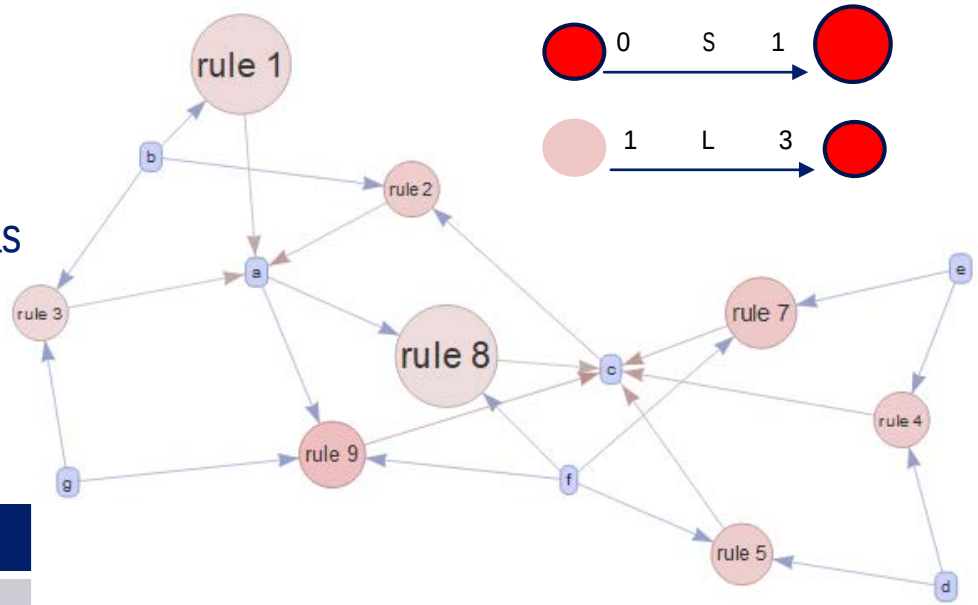
Advanced Design and Information Control Technologies

- Technologies i j and h are completely separated from the rest of the network and it has the higher lift with 2.13.
- Virtual technologies and Resource planning usually go hand in hand as shown in rule 2.

Estimated Rules Network C>0.765



Rules	Description	S	C	L
8	af => c	0.095	0.77	1.78
2	bc => a	0.053	0.90	1.82
6	ij => h	0.064	0.77	2.13

a. CAE, CAM, Virtual Product development
b. Virtual manufacturing
c. Enterprise Resource Planning (ERP)
d. Manufacturing Execution System
e. Software Integration of quality results
f. Manufacturing Resource Planning
g. Extranet and EDI
h. Wireless communications for production
i. Sensor network and integration
j. Computer integrated manufacturing
k. Automated systems for inspection
l. Unmanned aerial system (drone)


Q15_network.html

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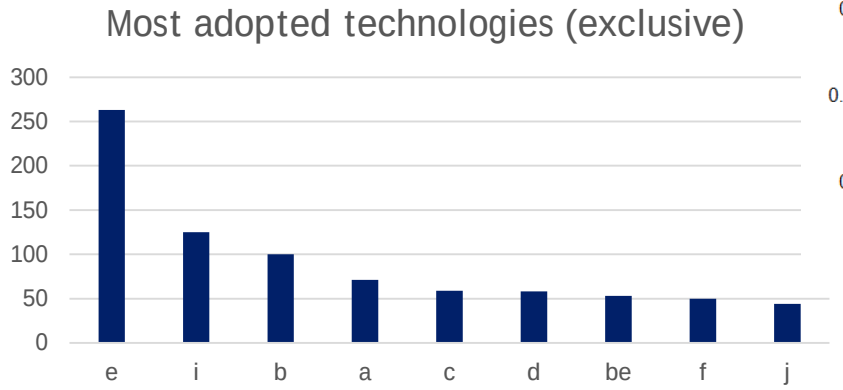
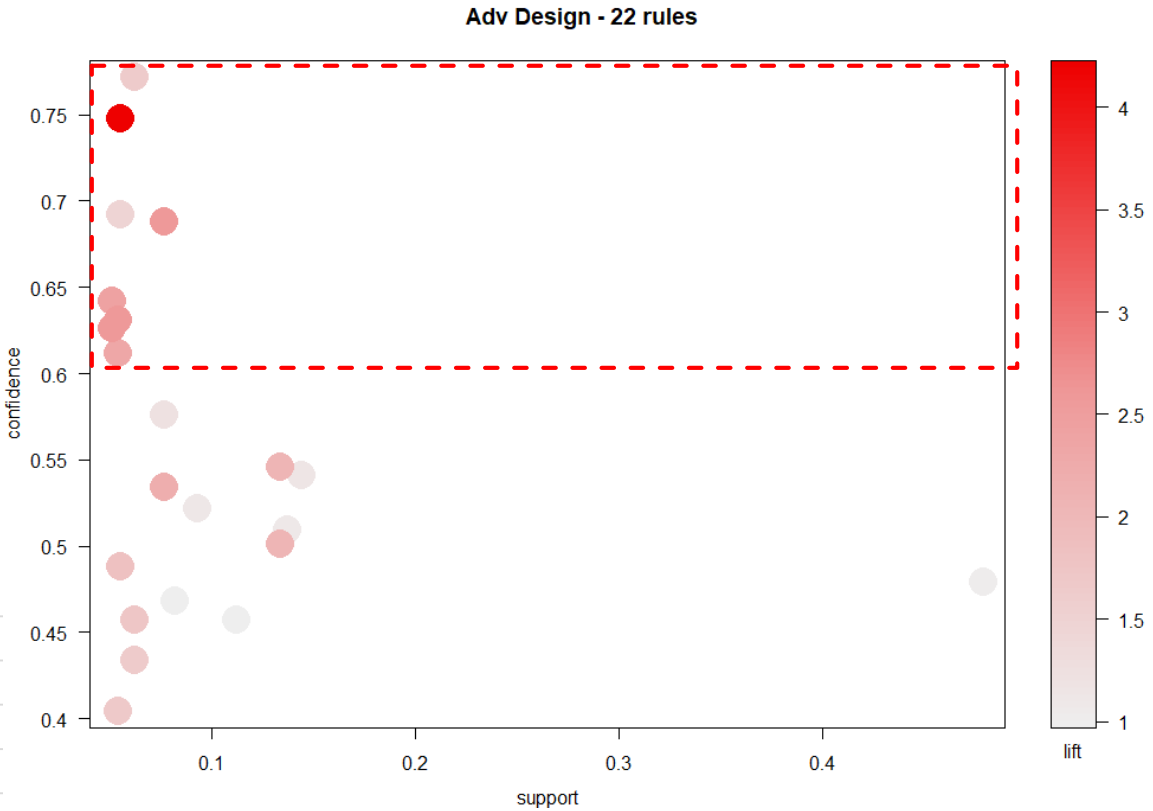
Advanced Processing and Fabrication technologies

- 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

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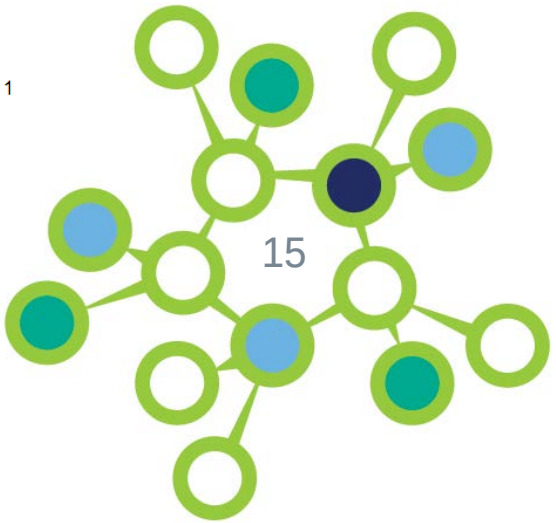
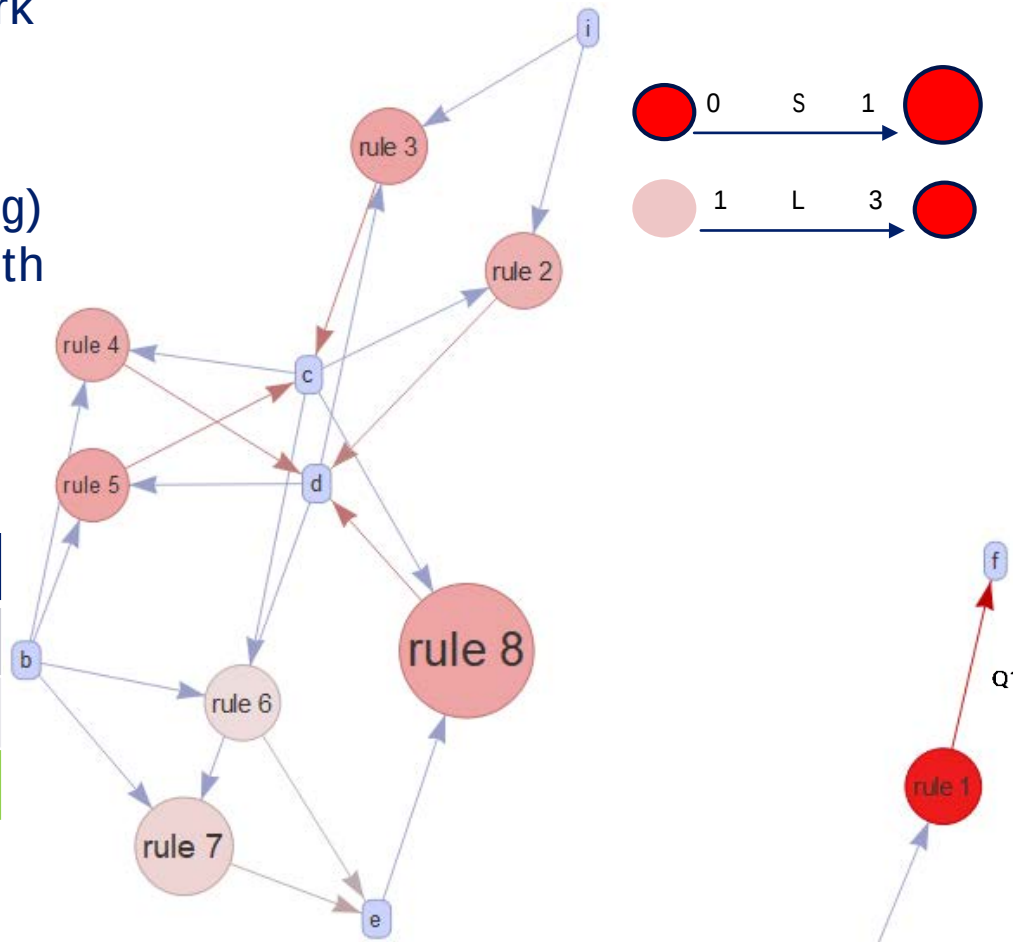


Advanced Processing and Fabrication technologies

- 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



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

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
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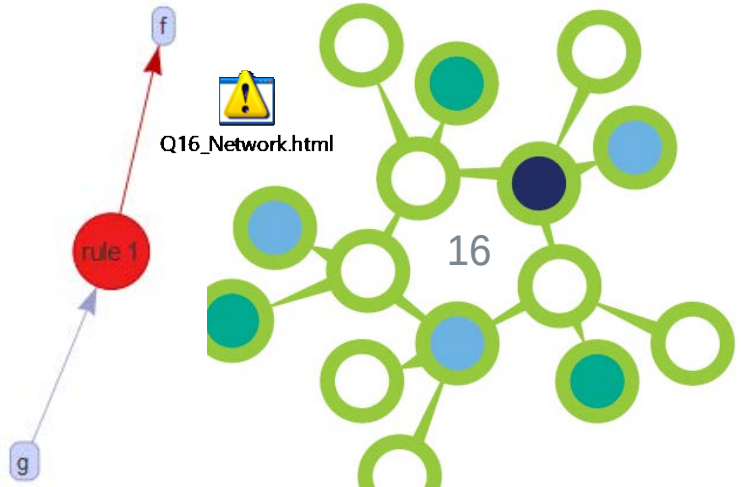

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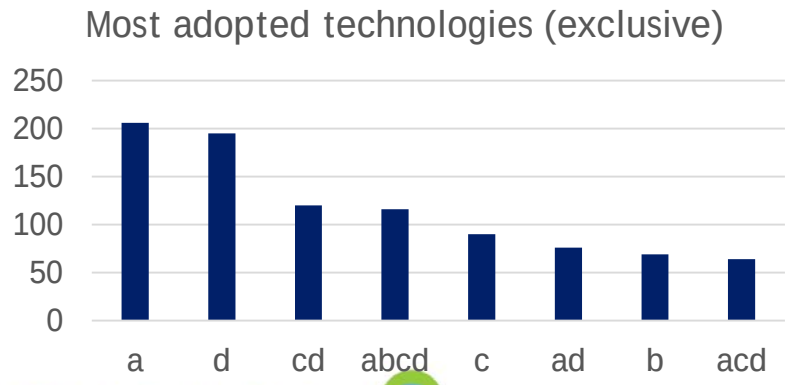
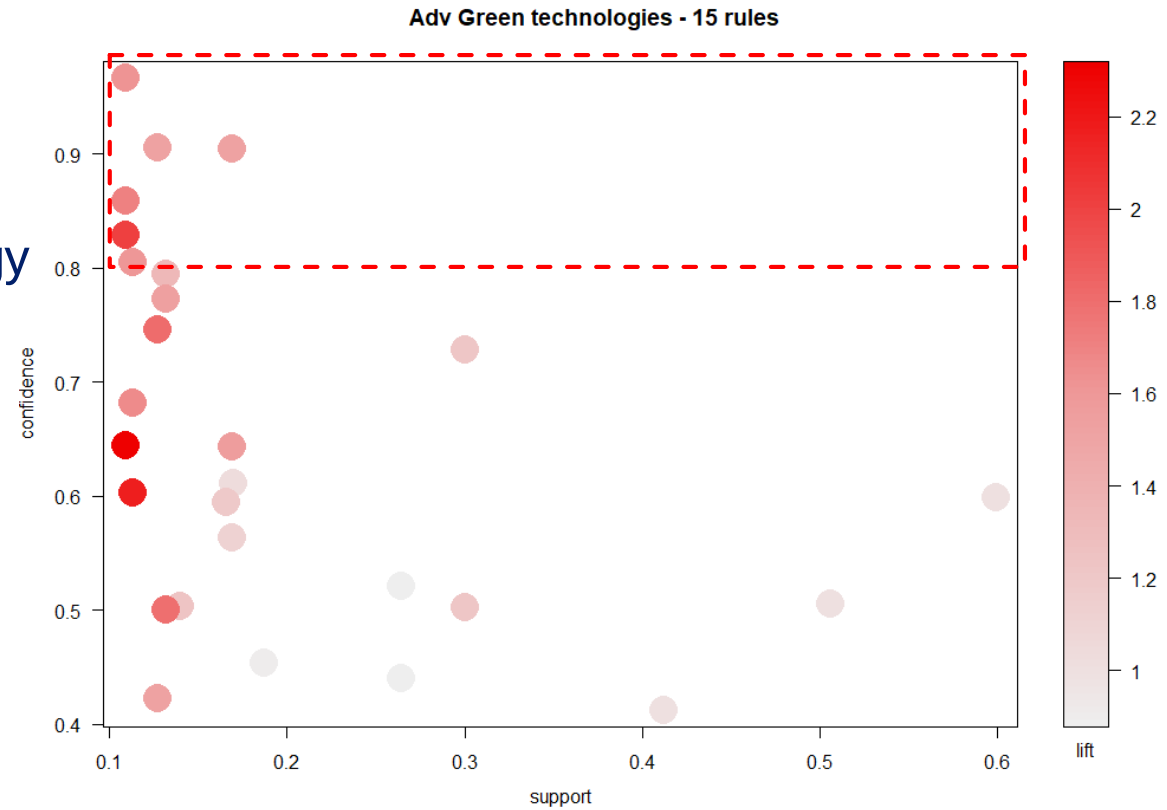
Advanced Green technologies

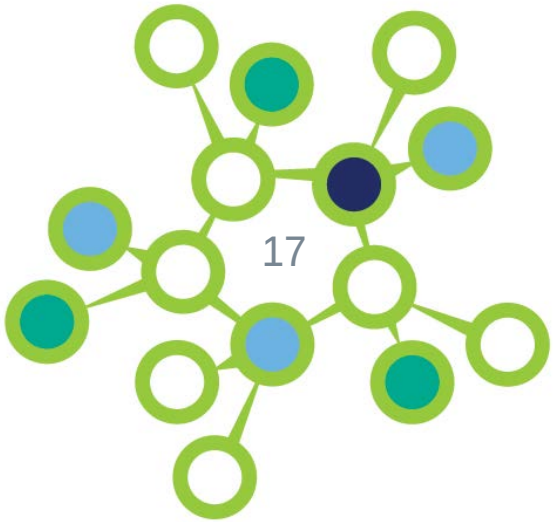
- Firms prefer to adopt two or more technologies in this category
- A combination of all technology is a popular choice amongst firms. Water and waste technologies seem to go together often as well (c,d)





a. Air of emission technologies
b. Energy Technologies
c. Water Technologies
d. Waste Technologies

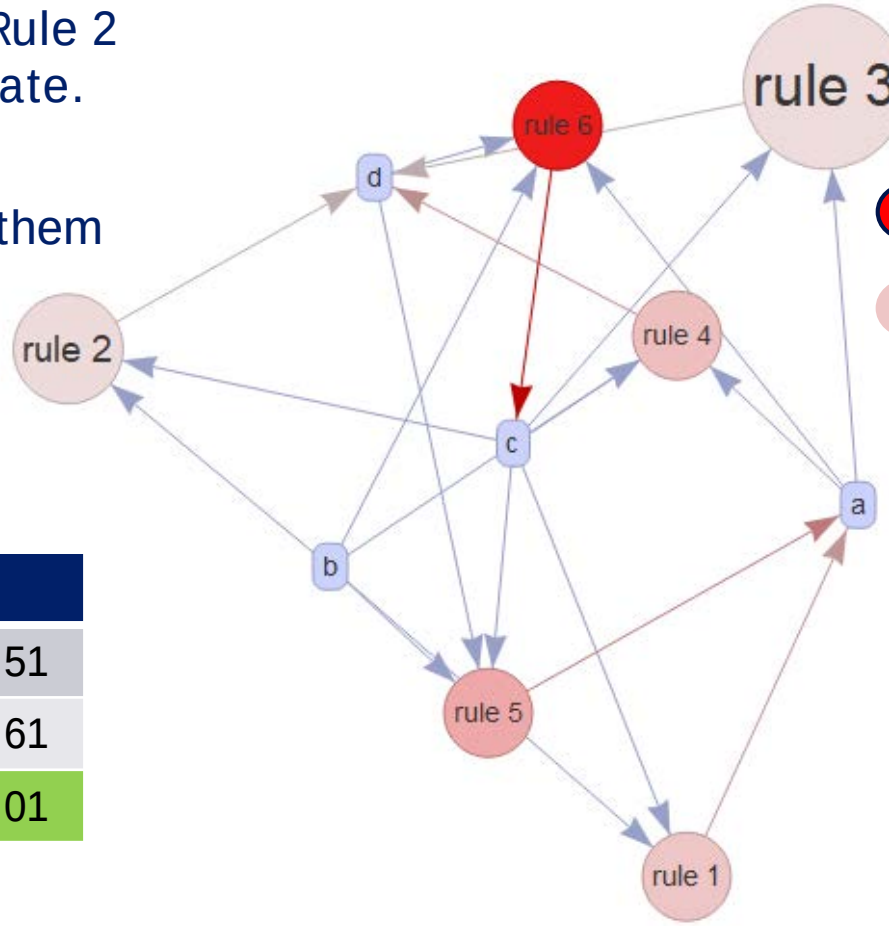
- When we filter with C>0,4 we obtain 15 rules
- The graph shows us that there are six at C>0.8
- In this case, we choose to use C>0.8 to get the most accurate rules



Advanced Green technologies

- The four technologies adopted together are a popular choice. Rule 2 shows almost 100% confidence rate.
- Only 1062 firms adopted green technologies but almost 17% of them adopted technologies a c and d, which is by far the highest S as showed in rule 3.

Estimated Rules Network C>0.8



a. Air of emission technologies
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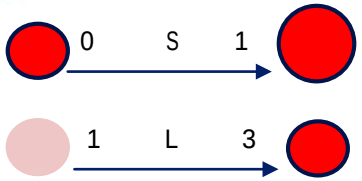
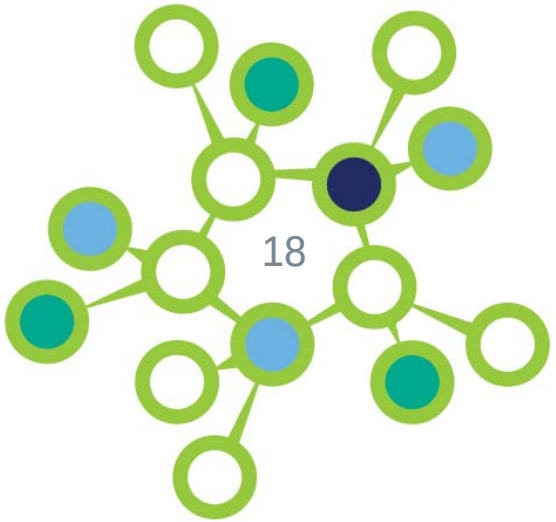


Rules	Description	S	C	L
3	ac => d	0.169	0.91	1.51
2	abc => d	0.109	0.97	1.61
6	abd => c	0.109	0.83	2.01



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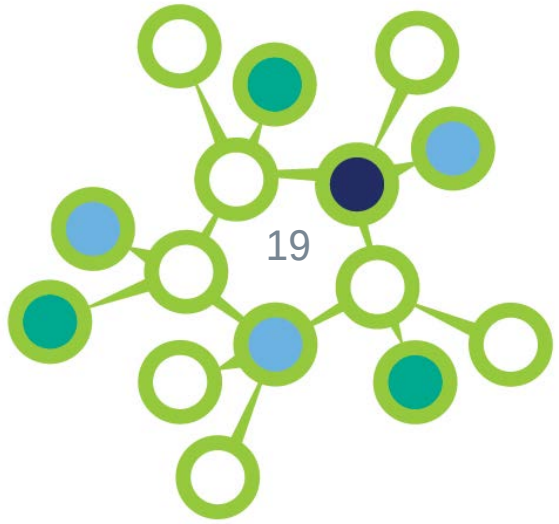
Effect on the adoption on innovation

Advanced Material Handling and Business Intelligence technologies



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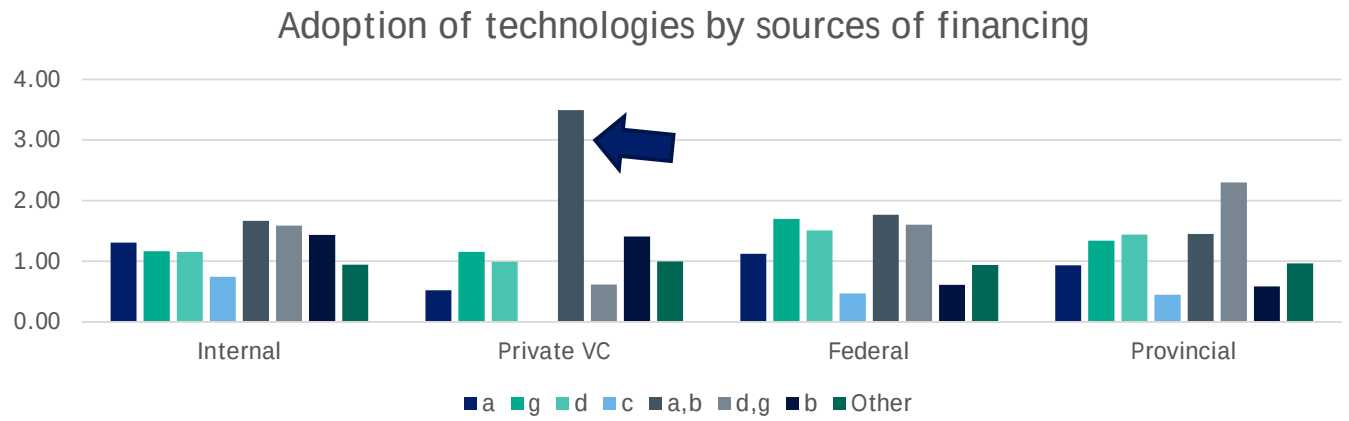
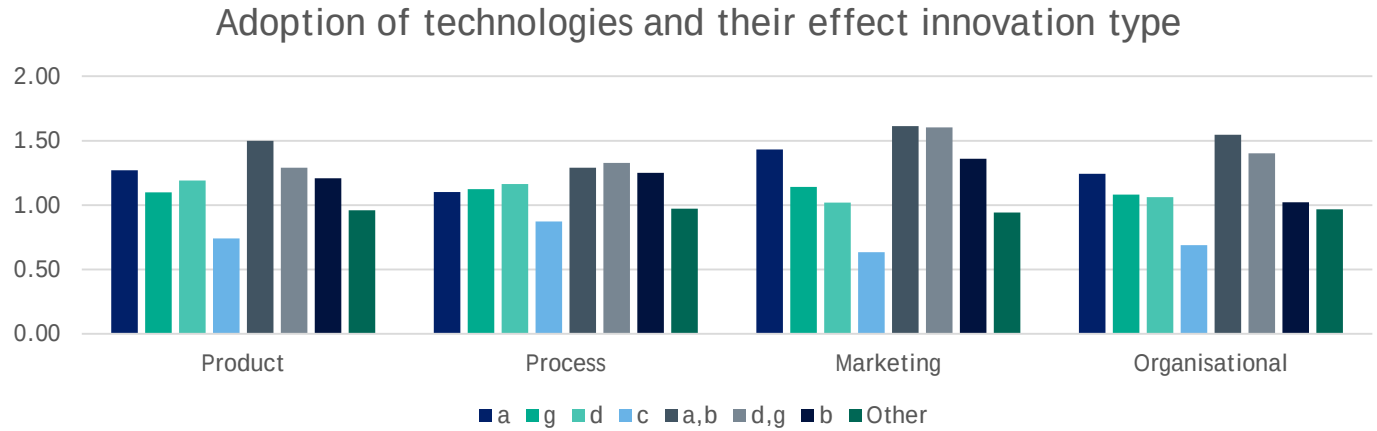
Advanced Material Handling, Supply Chain and Logistics technologies





- Firms who adopt technologies a,b receive 3.5 times more funding from private VCs than firms who adopt other technologies. The same trend is seen in other sources of financing
- Technology c receives less funding than other technologies in all sources of financing
- Technology c when adopted has a negative effect on firms in terms of innovation. These firms are less likely to innovate
- The adoption of technologies d,g and a,b have a positive impact on innovation

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a. CRM software
b. Software for demand forecasting
c. Transportation management system
d. Warehouse Management System
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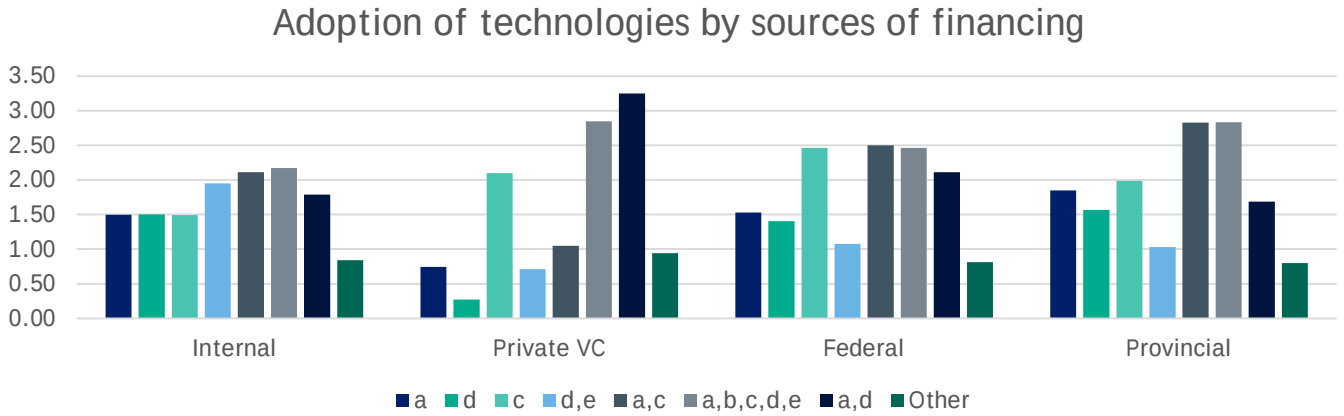
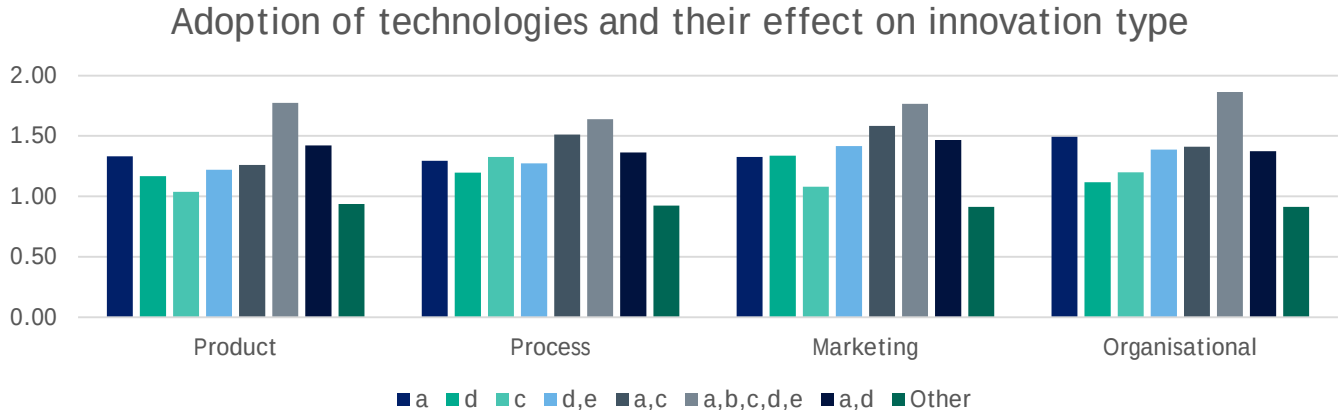
Advanced Business Intelligence technologies



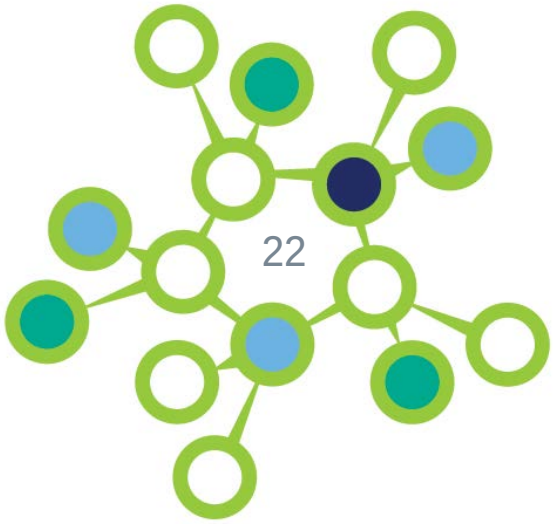


- Firms who adopt technologies a,b,c,d,e and a,d receive more funding than firms who adopt other technologies, especially from private VCs.
- Technology c receives less funding than other technologies in all sources of financing
- All groups of technologies showed have an increased innovation performance when adopted compared to firms that adopt other technologies or nothing at all.
- Technology c only seems to have a positive effect on process innovations

a. Executive dashboards for data analytics and decision making
b. Software for large scale data processing (e.g. Hadoop)
c. Live-stream processing technology or real-time monitoring
d. Software as a service (AaaS) and cloud computing software
e. Infrastructure as a service (IaaS) and cloud computing hardware

Conclusion and future research

- It is difficult to draw conclusions based on large networks. Therefore, we need to filter rules by using higher thresholds for support and confidence
- As a next step, regressions are needed understand which group of technologies have an effect on innovation performance
- Furthermore, experimentation is required to be able to use decision trees or neural networks to predict which technologies a firm should adopt to enhance its innovation performance based on key characteristics (R&D expenses, size, age, etc.)
- A similar analysis can be repeated with SAT 2007 data to do a survival and growth analysis



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Thank you

Questions

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