Economic Complexity Workshop

31 January 2019

University of Cape Town

Outline of Workshop

- **Introduction + Economic Complexity** [Chris]
- **The Product Space** [Chris]
- **Practical Introduction to the Atlas of Economic Complexity** [Rob]
- **Applications of Economic Complexity** [Rob]

ECONOMIC COMPLEXITY

DEVELOPMENT POLICY
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The Philosophy of Economic Complexity

The notion of economic complexity, developed by the team of researchers from the Centre of International Development at Harvard University, poses an alternative way of thinking about economic development. It is a shift in thinking and approaching development along the following lines:

- A shift away from the aggregate (e.g. GDP) toward the granular (e.g. products)
- A shift away from thinking about production being about the combining of factors of production, toward production being about the combining of knowledge/know-how/capabilities
- A modern reinterpretation of Adam Smith's division of labour toward the division of knowledge or know-how.

In this framework, knowledge/know-how is important in explaining development. A number of points warrant mention:

The Philosophy of Economic Complexity

Firstly, the extent of knowledge is not a function of the amount of knowledge embedded within any individual. Rather it is a function of the diversity of collective knowledge embedded across society and the ability of society to bring this knowledge together in complex networks of interactions.

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The Philosophy of Economic Complexity

Secondly, the diffusion of tacit knowledge acts as a constraint to development.

The Philosophy of Economic Complexity

Thirdly, large amounts of productive knowledge require increasingly complex webs of human interaction.

The Philosophy of Economic Complexity

Fourthly, development is about the accumulation of know-how, which is expressed in the production of a greater diversity of increasingly complex products.

Growth and development does not flow from specialisation according to comparative advantage, but rather by the growth in productive knowledge that leads to an increasingly diverse and complex economy.

"***Complex economies*** *are those that can* ***weave vast quantities*** *of relevant* ***knowledge*** *together, across* ***large networks*** *of people, to generate a* ***diverse*** *mix of* ***knowledge-intensive products***. ***Simpler economies***, *in contrast, have a* ***narrow base of productive knowledge*** *and* ***produce fewer*** *and* ***simpler products***, *which require* ***smaller webs of interaction***. *Because individuals are limited in what they know, the only way societies can expand their knowledge base is by facilitating the interaction of individuals in increasingly complex webs of organizations and markets. Increased economic complexity is necessary for a society to be able to hold and use a larger amount of productive knowledge, and* ***we can measure it from the mix of products that countries are able to make***."

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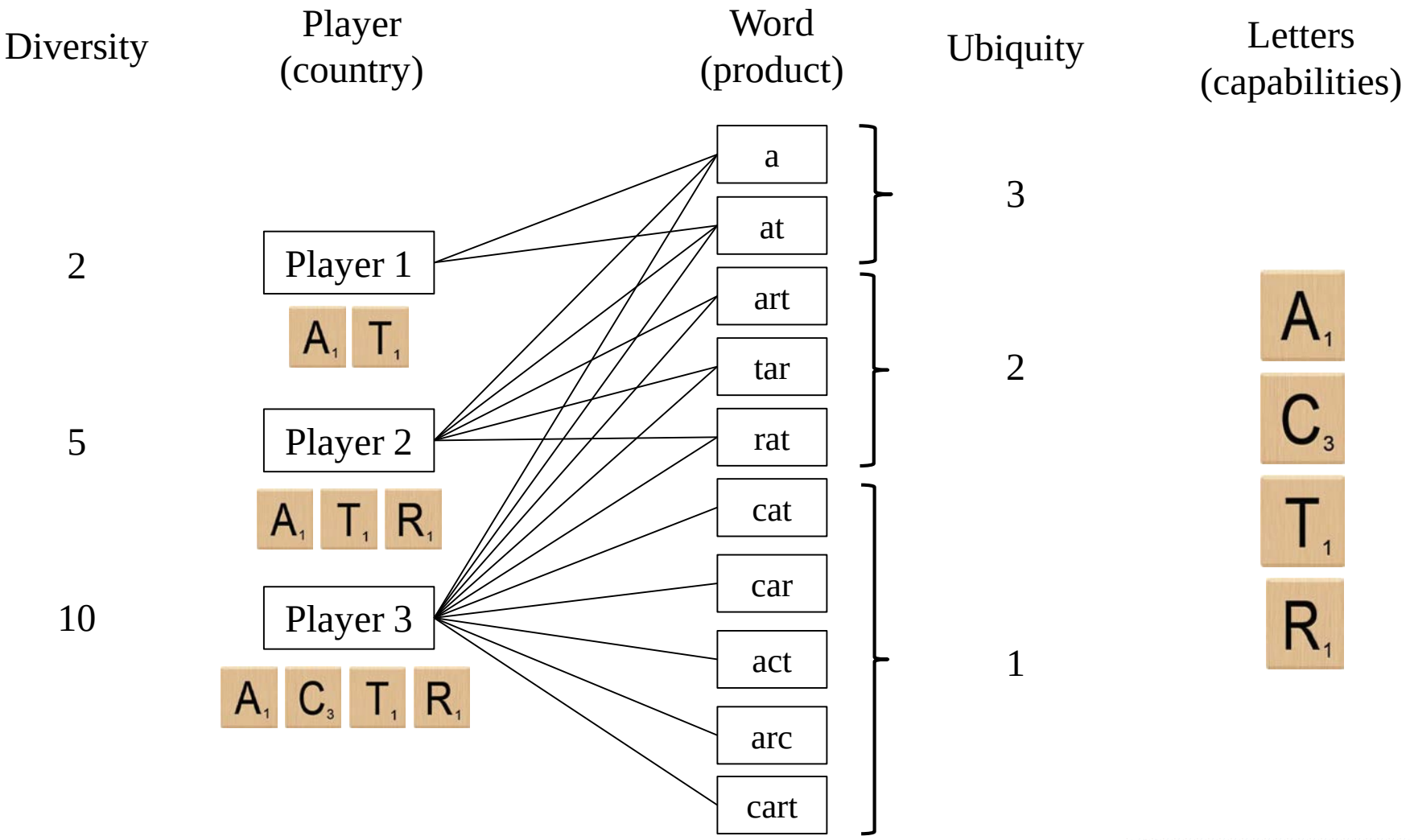
Generating a Measure of Economic Complexity

- The authors of the Atlas of Economic Complexity argue that productive knowledge is the key to prosperity, and that large amounts of productive knowledge require complex webs of human interaction, which they call economic complexity.
- They then go on to developing a method for measuring the amount of productive knowledge held by different societies.
- However, there is no direct means of observing how much productive knowledge is embedded in an economy.
- Therefore, they adopt an indirect approach – they look at what countries make, and from this, infer what a country knows.
- This can be understood using the scrabble illustration…

Generating a Measure of Economic Complexity

The intuition behind Economic Complexity: The Scrabble analogy



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Generating a Measure of Economic Complexity

- Therefore, diversity and ubiquity provide insight into the productive knowledge or capabilities embodied in a country and product, respectively.
- BUT, the diversity of a country's exports is a crude approximation of the variety of capabilities available in the country, just as the ubiquity of a product is a crude approximation of the variety of capabilities required by a product.
- E.g. medical imaging devices versus diamonds
  - Both products are made by only a few countries (i.e. scarce or low ubiquity)
  - BUT, medical imaging devices are made by Germany and USA, which have diverse export portfolios, suggesting many capabilities, and thus one can infer complexity upon the product.
  - CONVERSELY, diamonds are made by Botswana and Sierra Leone, which have relatively concentrated export portfolios, suggesting limited capabilities, and thus one cannot infer complexity on this product (something else is driving scarcity)
  - THEREFORE, one can use the diversity of countries making a product (diamonds) to nuance the first impression given by the ubiquity (low) of the product.

Generating a Measure of Economic Complexity

- Similarly, one can use the ubiquity of the products that a country makes to improve the first impression of its complexity given by its diversity – e.g. Egypt versus Switzerland
  - Diversity = 180 products for both countries
  - Egypt exports products that are on average exported by 28 other countries versus Switzerland exports products that are on average exported by 19 other countries.
  - Furthermore, the products exported by Switzerland are exported by highly diversified countries versus the products exported by Egypt are exported by poorly diversified countries.
- One can improve the estimate of the productive knowledge of a country that is inferred from its diversity by looking at the ubiquity of the products that it makes. This estimate can be further refined by looking at the diversity of the countries that make these products, and the ubiquity of the products that these countries make.
- Similarly, one can improve the estimate of the productive knowledge embodied in a product that one infers from its ubiquity by looking at the diversity of the countries that make this product. This can be refined further by looking at the ubiquity of the other products made by the countries that make this product.
- This can be done an infinite number of times using a mathematical process that the authors of the Atlas call the Method of Reflections.
- This process converges after a few iterations and generates the quantitative measures for complexity – ECI and PCI

Generating a Measure of Economic Complexity

The Method of reflections is an iterative procedure involving the following equations…

$$Diversity = \ k_{c,0} = \sum_{p} M_{cp}$$

$$Ubiquity = \ k_{p,0} = \sum_{c} M_{cp}$$

To generate a more accurate measure of the number of capabilities available in a country, or required by a product, these recursions correct the information carried by ubiquity and diversity:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} \cdot k_{p,N-1} \quad (1)$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} \cdot k_{c,N-1} \quad (2)$$

Note: $M_{cp} = 1$ if $RCA_{cp} \geq 1$

Generating a Measure of Economic Complexity

Insert (2) into (1) to obtain

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} \frac{1}{k_{p,0}} \sum_{c'} M_{c'p} \cdot k_{c',N-2}$$

$$k_{c,N} = \sum_{c'} k_{c',N-2} \sum \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}}$$

And rewrite the equation as

$$k_{c,N} = \sum_{c'} \widetilde{M_{cc'}} \, k_{c',N-2}$$

where

$$M_{cc'} = \sum_{P} \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}}$$

This is satisfied when $k_{c,N} = k_{c,N-2} = 1$. This corresponds to the eigenvector of $M_{cc'}$ which is associated with the second largest eigenvalue. Since this eigenvector is a vector of ones, it is not informative. Instead, one looks for the eigenvector associated with the second largest eigenvalue. This is the eigenvector that captures the second largest amount of variance in the system and is the measure of ECI. The ECI index is defined as:

$$ECI = \frac{\vec{K} - \langle \vec{K} \rangle}{stdev(\vec{K})}$$

where

$$\vec{K} = Eigenvector\ of M_{cc'}\ associated with\ the\ second\ largest\ eigenvalue$$

Analogously for PCI

Generating a Measure of Economic Complexity

Let’s look at a simple numeric example showing how the calculation works…

Generating a Measure of Economic Complexity

Method of reflections: simple example

$$k_{c,0} = \sum_{p} M_{cp}$$

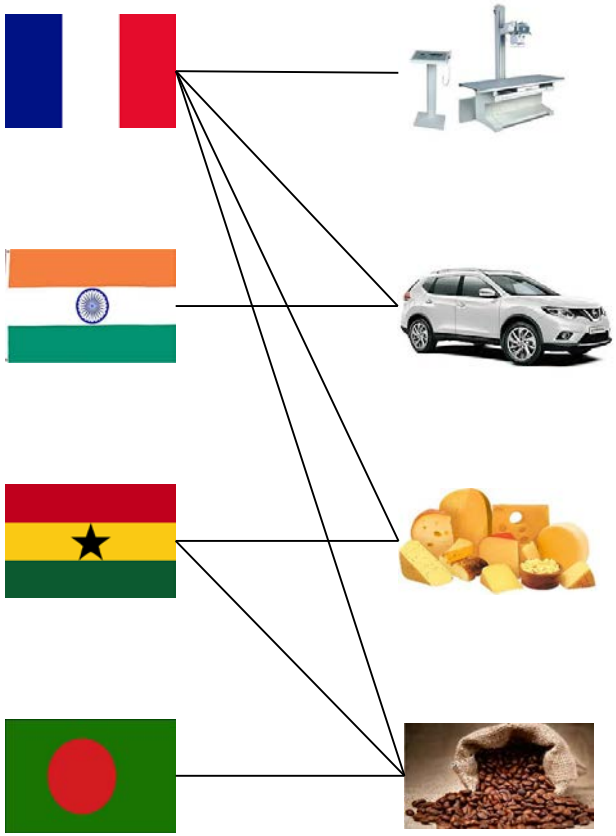
$$k_{p,0} = \sum_{c} M_{cp}$$

$k_{c1,0} = 4$

$k_{c2,0} = 1$

$k_{c3,0} = 2$

$k_{c4,0} = 1$



$k_{p1,0} = 1$

$k_{p2,0} = 2$

$k_{p3,0} = 2$

$k_{p4,0} = 3$

Diversity

Ubiquity

Mcp	X-ray	Car	Cheese	Coffee
FRA	1	1	1	1
IND	0	1	0	0
GHA	0	0	1	1
BGD	0	0	0	1

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Generating a Measure of Economic Complexity

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} \cdot k_{p,N-1}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_c M_{cp} \cdot k_{c,N-1}$$

1st reflection

$$k_{c,1} = \frac{1}{k_{c,0}} \sum_p M_{cp} \cdot k_{p,0} \qquad k_{c,0} = \sum_p M_{cp}$$

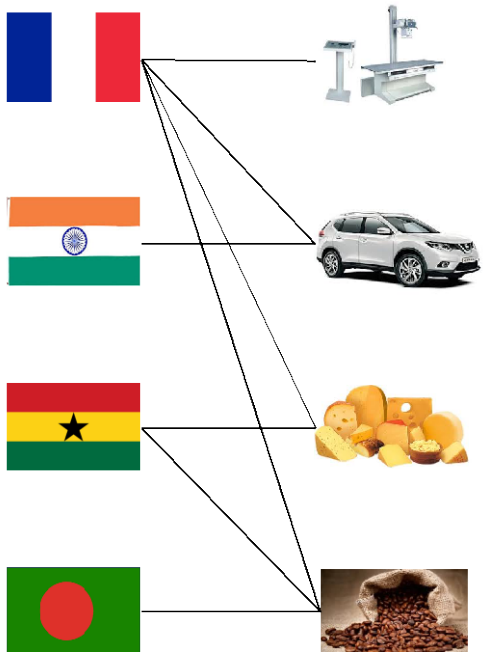
$$k_{p,0} = \sum_c M_{cp} \qquad k_{p,1} = \frac{1}{k_{p,0}} \sum_c M_{cp} \cdot k_{c,0}$$

$k_{c1,1} = (\frac{1}{4})(1 + 2 + 2 + 3) = 2$ $\quad k_{c1,0} =$ $\quad k_{p1,0} =$ $\quad k_{p1,1} = (\frac{1}{1})(4) = 4$

$k_{c2,1} = \left(\frac{1}{1}\right)(2) = 2$ $\quad k_{c2,0} =$ $\quad k_{p2,0} =$ $\quad k_{p2,1} = \left(\frac{1}{2}\right)(4 + 1) = 2.5$

$k_{c3,1} = \left(\frac{1}{2}\right)(2 + 3) = 2.5$ $\quad k_{c3,0} =$ $\quad k_{p3,0} =$ $\quad k_{p3,1} = \left(\frac{1}{2}\right)(4 + 2) = 3$

$k_{c4,1} = \left(\frac{1}{1}\right)(3) = 3$ $\quad k_{c4,0} =$ $\quad k_{p4,0} =$ $\quad k_{p4,1} = \left(\frac{1}{3}\right)(4 + 2 + 1) = 2.33$



Avg. ubiquity of products exported by country c

Mcp	X-ray	Car	Cheese	Coffee
FRA	1	1	1	1
IND	0	1	0	0
GHA	0	0	1	1
BGD	0	0	0	1

Avg. diversity of countries exporting product p

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Generating a Measure of Economic Complexity

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} \cdot k_{p,N-1}$$

$$k_{c,2} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} \cdot k_{p,1}$$

2nd reflection

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} \cdot k_{c,N-1}$$

$$k_{p,2} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} \cdot k_{c,1}$$

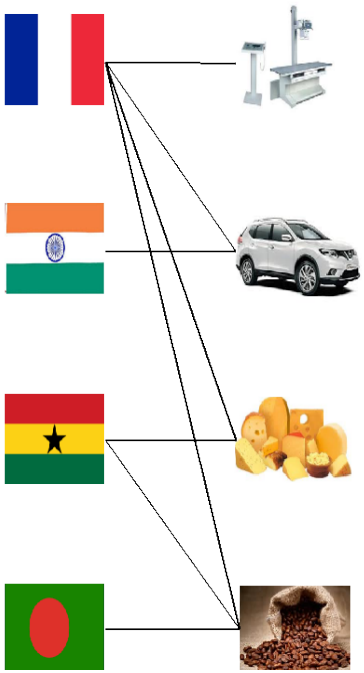
$k_{c1,2} = \left(\frac{1}{4}\right)(4 + 2.5 + 3 + 2.33)$ $k_{c1,1} =$ $k_{c1,0} = 4$

$= 2.96$

$k_{c2,2} = \left(\frac{1}{1}\right)(2.5) = 2.5$ $k_{c2,1} =$ $k_{c2,0} = 1$

$k_{c3,2} = \left(\frac{1}{2}\right)(3 + 2.33) = 2.66$ $k_{c3,1} =$ $k_{c3,0} = 2$

$k_{c4,2} = \left(\frac{1}{1}\right)(2.33) = 2.33$ $k_{c4,1} =$ $k_{c4,0} = 1$



$k_{p1,0} = 1$ $k_{p1,1} =$ $k_{p1,2} = \left(\frac{1}{1}\right)(2) = 2$

$k_{p2,0} = 2$ $k_{p2,1} =$ $k_{p2,2} = \left(\frac{1}{2}\right)(2 + 2) = 2$

$k_{p3,0} = 2$ $k_{p3,1} =$ $k_{p3,2} = \left(\frac{1}{2}\right)(2 + 2.5) = 2.25$

$k_{p4,0} = 3$ $k_{p4,1} =$ $k_{p4,2} = \left(\frac{1}{3}\right)(2 + 2.5 + 3) = 2.5$

Mcp	X-ray	Car	Cheese	Coffee
FRA	1	1	1	1
IND	0	1	0	0
GHA	0	0	1	1
BGD	0	0	0	1

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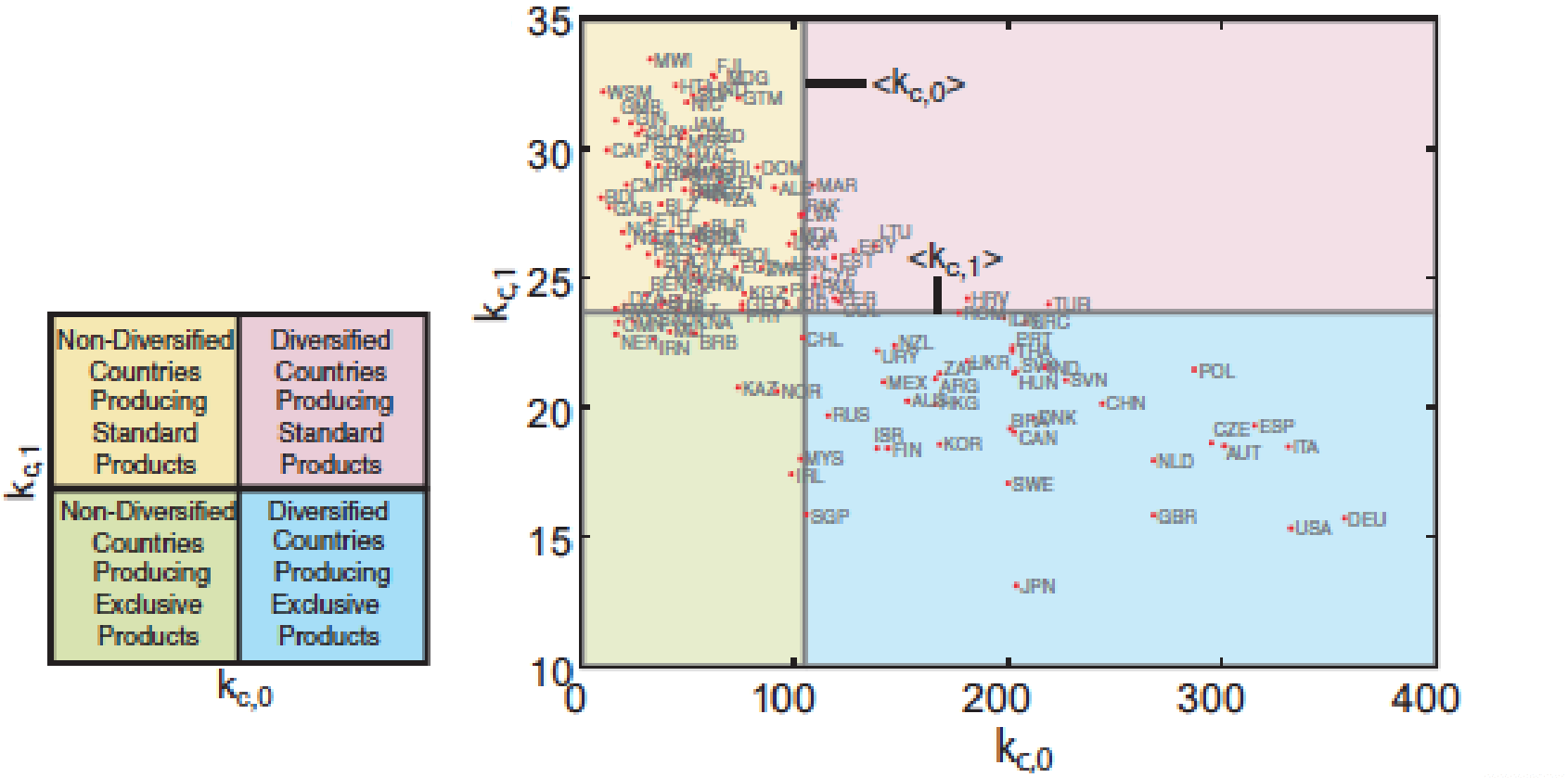
Generating a Measure of Economic Complexity
The link between $k_{c,0}$ and $k_{c,1}$

Diversified countries tend to produce less ubiquitous products



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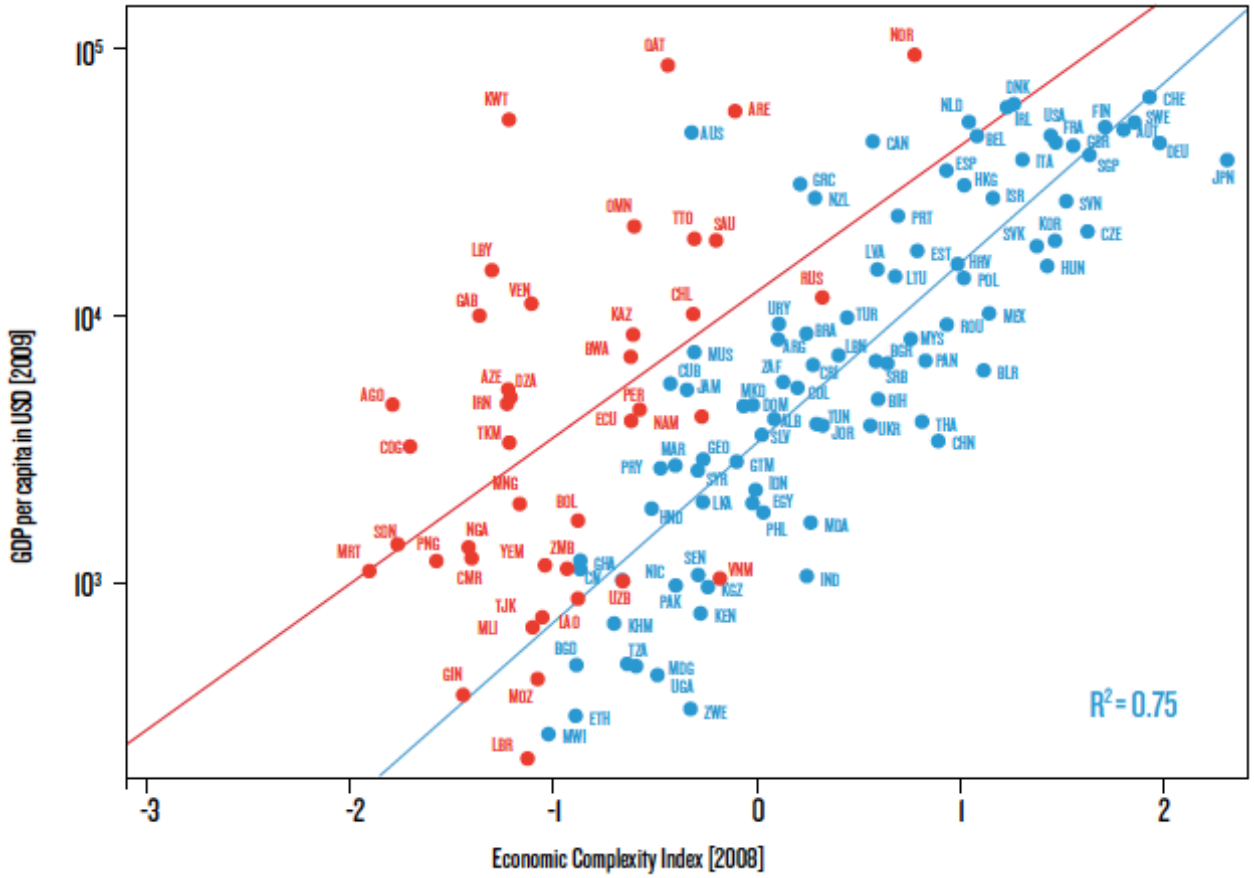
Source: Extracted from Hidalgo, Hausmann & Dasgupta (2009)

The Relevance of Economic Complexity



There is a strong correlation between ECI and GDP per capita

75% of variance in GDP p.c. among minor natural resource exporters explained by ECI

BUT, red lines shows that a large presence of natural resources allows a country to be relatively rich without being complex

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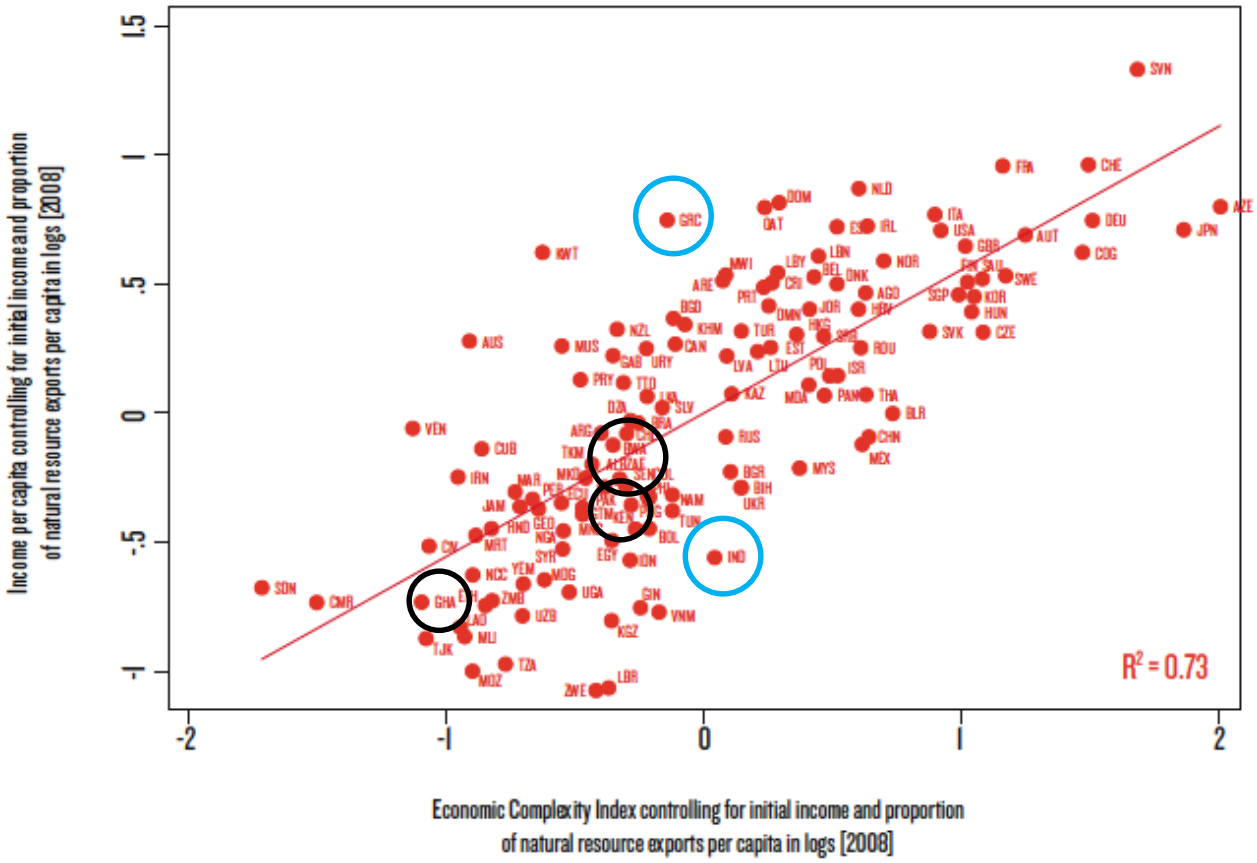
The Relevance of Economic Complexity



Nevertheless, after controlling for each country's natural resource exports, ECI and natural resource exports explain 73% of variation in GDP p.c. across countries.

Therefore, the more complex a country, the more likely a country has a higher level of income.

BUT, this relationship is not perfect – countries fall above and below the regression line.

Greece versus India

Countries whose ECI is greater than what one would expect given their current level of income, tend to grow faster than those that are 'too rich' for their current level of ECI

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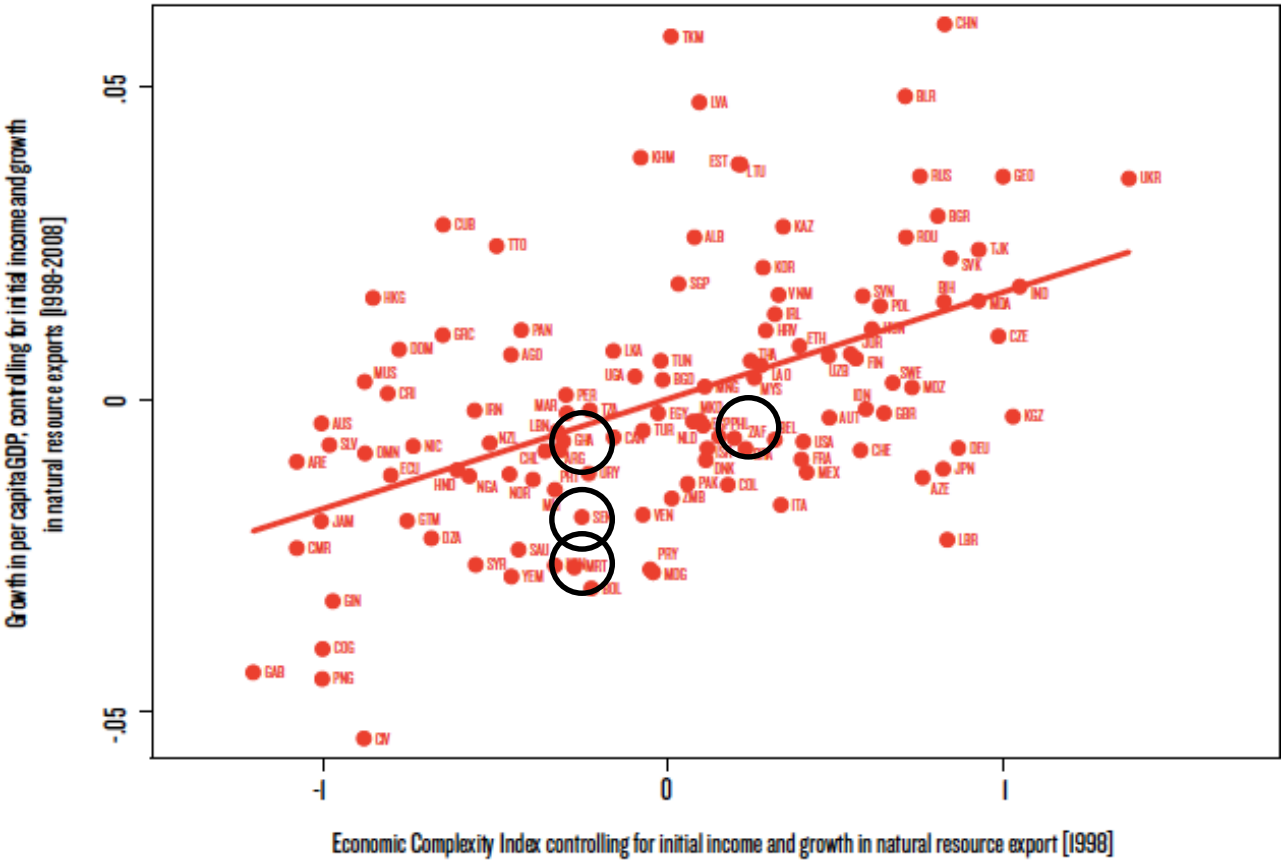
The Relevance of Economic Complexity



Economic complexity precedes and hence drives L/R levels of income and growth.

Countries tend to move toward the level of income that is compatible with their overall level of productive knowledge.

Growth equation estimations in Hidalgo & Hausmann (2009) confirm this.

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The Relevance of Economic Complexity

Rank	Country	Economic Complexity Index
1	Japan	2.61
2	South Korea	2.37
3	Switzerland	2.33
4	Singapore	2.25
5	Germany	1.89
6	Hong Kong	1.47
7	Czech Republic	1.42
8	United States	1.42
9	United Kingdom	1.36
10	Hungary	1.24
11	Israel	1.17
12	Slovakia	1.16
13	Italy	1.13
14	France	1.13
15	Malaysia	1.12
16	Ireland	1.10
17	China	1.00
18	Belgium	0.97
19	Mexico	0.75
20	Poland	0.67

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References: Economic Complexity

The section discussing economic complexity is informed by the following sources:

- Hausmann, R., Hidalgo, C.A., Bustos, S., Coscia, M., Simoes, A. & Yildirim, M. 2014. The Atlas of Economic Complexity: Mapping Paths to Prosperity, Cambridge, Massachusetts: MIT Press. http://atlas.media.mit.edu/static/pdf/atlas/AtlasOfEconomicComplexity.pdf
- Hidalgo, C.A., Hausmann, R. & Dasgupta, P.S., 2009. The building blocks of economic complexity. *Proceedings of the National Academy of Sciences of the United States of America*, 106(26), pp.10570–10575. Available at: http://www.jstor.org/stable/40483593.
- Hausmann, R. & Hidalgo, C. a., 2011. The network structure of economic output. *Journal of Economic Growth*, 16(4), pp.309–342.

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THE PRODUCT SPACE

How to grow complexity?

Complexity seems to matter: 1) it affects a country's level of income per capita, and 2) it drives future growth. But…

- How does complexity evolve?
- How do societies increase the amount of productive knowledge they have?
- How do they become more complex?
- What limits the speed of this process?

Complexity is a reflection of the amount of productive knowledge within a country. This knowledge is costly to acquire and transfer, and is modularised into chunks called capabilities. In order to produce new products, you need to accumulate new capabilities.

BUT, the accumulation of capabilities is complicated by the **chicken and egg problem**…

- You can't produce products that require capabilities that you do not have.
- BUT, there is no incentive to accumulate capabilities if the industries that demand them, do not exist.
- This is especially the case if the capabilities required by a new industry/product are numerous (thinking scrabble…you need a lot of letters to build a new word)

How to grow complexity?

How do countries accumulate capabilities, and thus produce the new products that require such capabilities ?

- New capabilities are more easily accumulated if they are combined with others that already exist (versus coordinating the accumulation of a wide range of capabilities).
- Countries are more likely to move into products that can make use of capabilities that the country already has and is using in existing industries
- This implies that countries will diversify by moving from the industries that already exist, to others that require a similar set of capabilities
  - i.e. it is easier to shift from shirts to blouses than from shirts to jet engines.
  - The embedded knowledge in shirts is similar to that of blouses but dissimilar to that of jet engines

How to grow complexity?

Problem:

- Since we do not observe capabilities directly, measuring the similarity in capability requirements of different products is not simple.

Solution:

- Create a measure that infers the similarity between capabilities required by a pair of products by looking at the probability that they are co-exported
  - The probability that a pair of products is co-exported, carries information about how similar these products are
  - $Pr(X_{blouses}|X_{shirts}) > Pr(X_{jet\ engines}|X_{shirts})$
- Key assumption: if two products share most of the requisite capabilities, the countries that export the one will also export the other. Relatedly, if the two products do not share many capabilities, then they are less likely to be co-exported
- Therefore, one is able to measure the proximity between all pairs of products
- The collection of all proximities is a network connecting pairs of products that are significantly likely to be co-exported by many countries
- This network is called the Product Space

The Concept of Proximity

Measuring proximity

Products are measured as highly proximate if they tend to be exported together.

Proximity between product i and j in year t equals:

$$\varphi_{i,j,t} = min\{P(x_{i,t}|x_{j,t}), P(x_{j,t}|x_{i,t})\}$$

where for any country c

$$x_{i,c,t} = \begin{cases} 1 \; if \; RCA_{i,c,t} > 1 \\ 0 \; otherwise \end{cases}$$

and where the conditional probability is calculated using all countries in year t.

This allows one to create a product-to-product network called a proximity matrix that is used to generate the product space.

or…

The Concept of Proximity

$$\varphi_{i,j} = \frac{\sum_c M_{ci} M_{cj}}{max(k_{i,0}, k_{j,0})}$$

where $M_{c,i} = 1$ if country c exports product i with $RCA > 1$ and 0 otherwise, and where $k_{i,0}$ is the ubiquity of product i.

Example:

17 countries export wine

24 export grapes

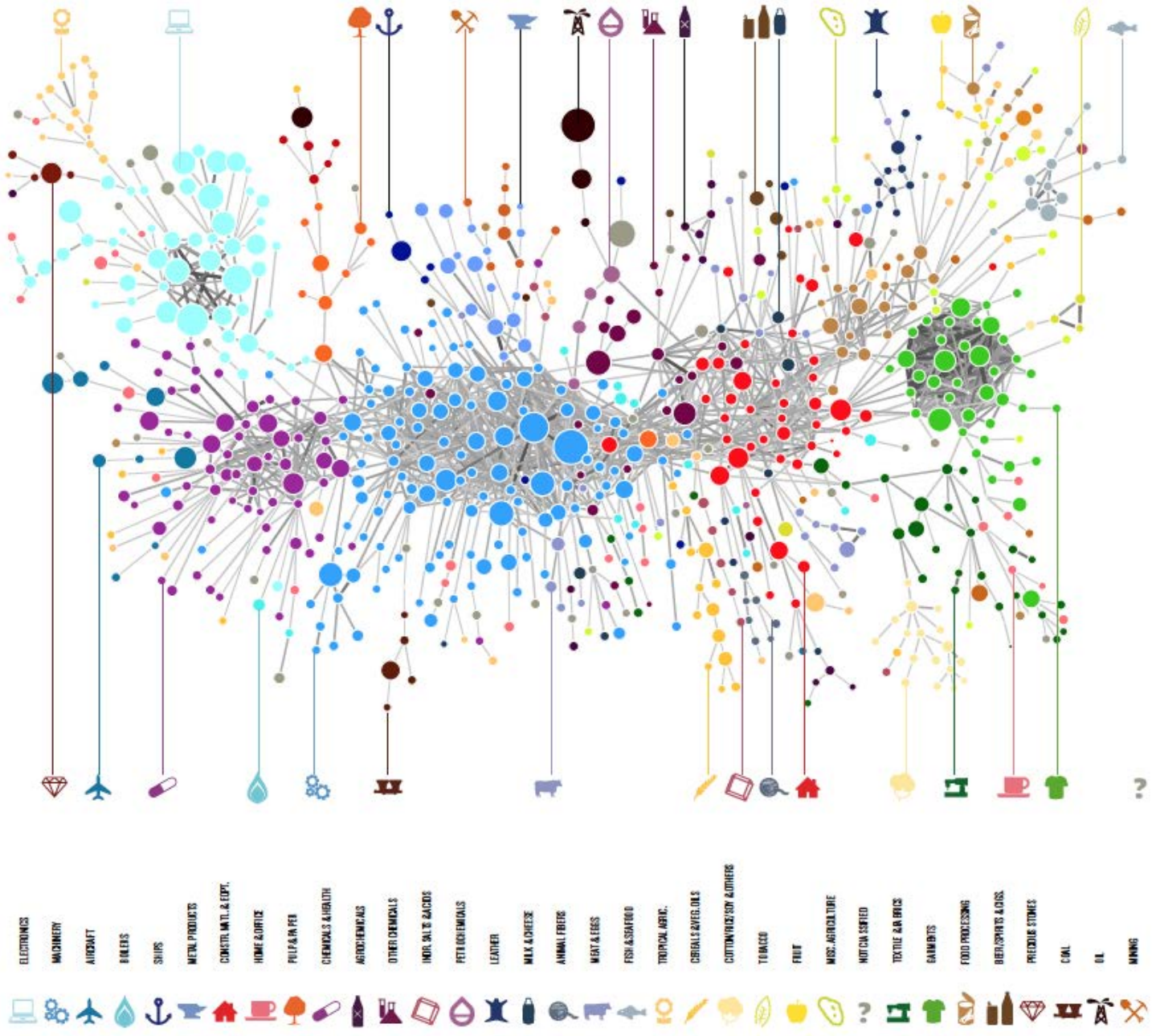
11 export both

11/17 = 0.65

11/24 = 0.46 – choose smallest conditional probability

Note: For more detail on how to create the product space, see Supplementary Online Material for the paper titled, 'The product space conditions the development of nations, co-authored by Hidalgo, Klinger, Barabasi and Hausmann.

Visualising the Product Space



What the Product Space can tell us?

The structure of a country's product space tells us how easily it can increase its complexity. In particular, its interesting to distinguish between core (tightly connected) and peripheral (sparsely connected) product spaces:

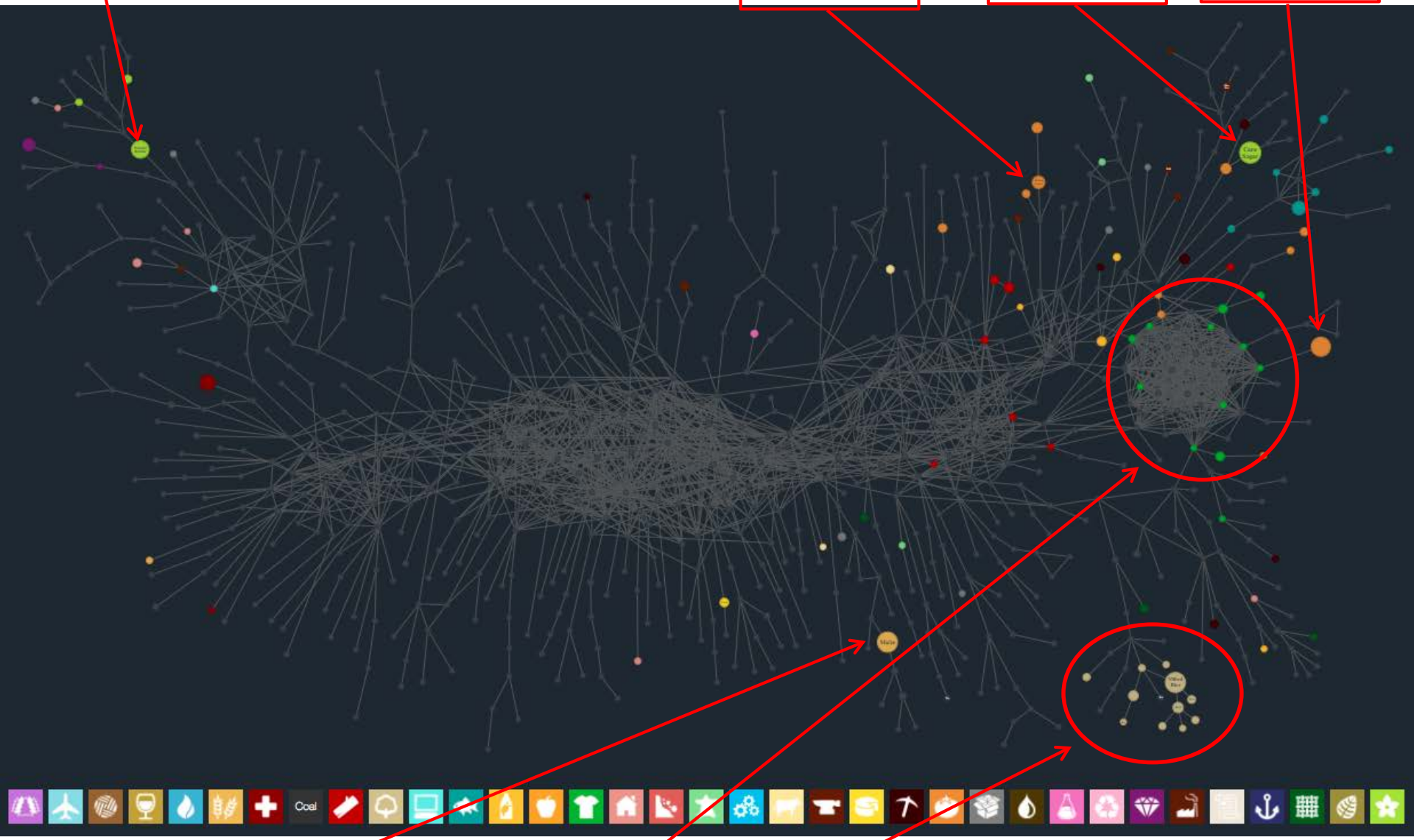
- If a country is in the core, then neighbouring products differ in few of their requisite capabilities. Easier to diversify by accumulating the few missing capabilities (chicken and egg problem less severe). Easier to grow complexity.
- If a country is in the periphery, then neighbouring products have less in common, implying that they use different capabilities. Harder to diversify because require simultaneous acquisition of multiple missing capabilities (chicken and egg problem is more of an issue). Harder to grow complexity

Furthermore, the product space suggests that structural transformation is a path dependent process. A country's current productive structure – and the knowledge embedded in it – impacts on its subsequent evolution.

- Countries find it easier to move to 'nearby' products

Let's look at some examples…

Product Space – Thailand (1975)



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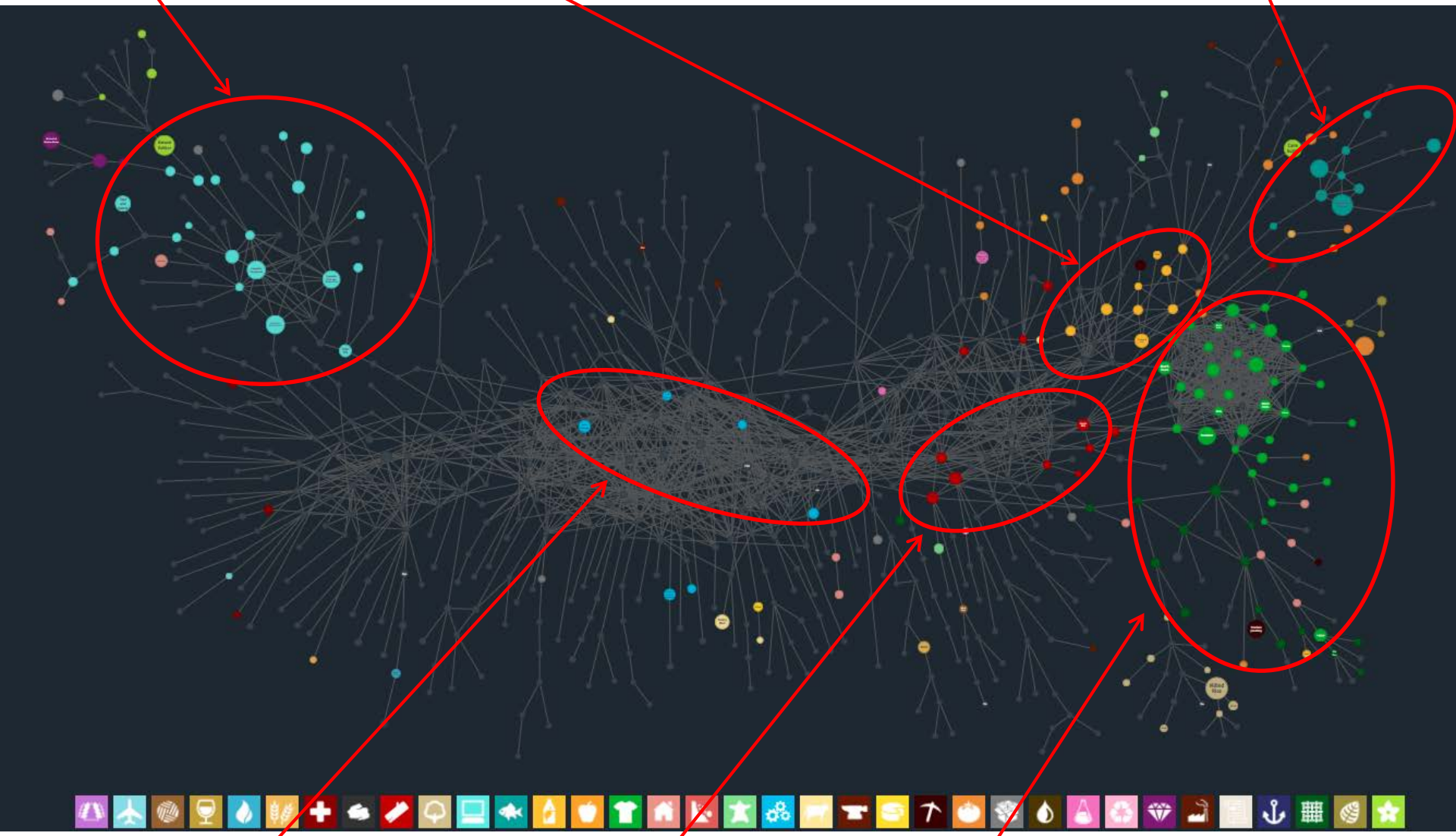
Product Space – Thailand (1990)

Electronics (e.g. Computer peripherals; electronic microcircuits)

Food processing (e.g. prepared fruit)

Fish & Seafood (e.g. crustaceans & moluscs)



Machinery (e.g. Roller bearings, Miscellaneous rubber)

Construction materials & equipment (e.g. electric wire, furniture)

Garments and Textiles & Fabrics

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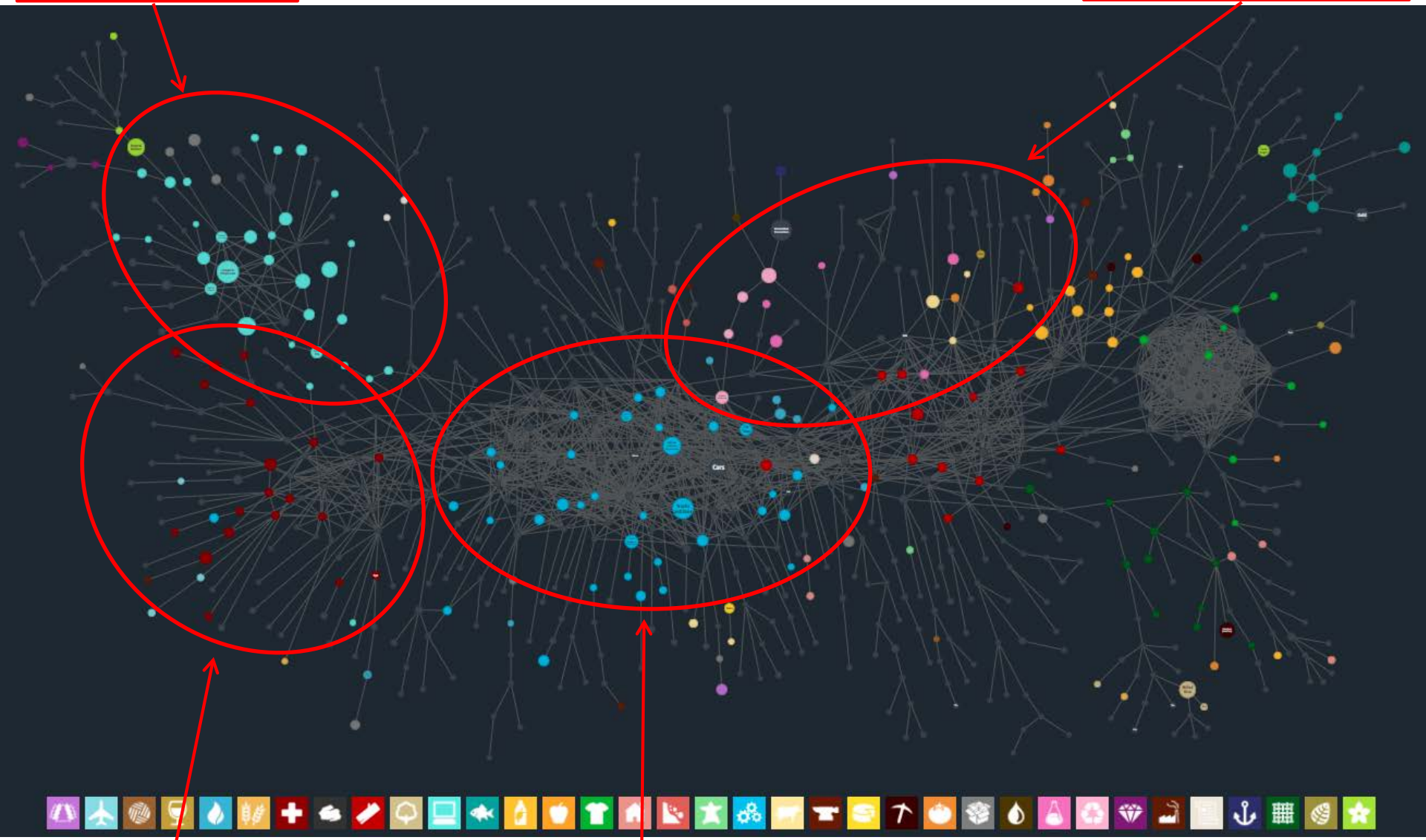
Product Space – Thailand (2014)

Electronics (e.g. Computer peripherals; electronic microcircuits)

Other Chemicals and Petrochemicals



Chemicals & Health related products (e.g. Cyclic hydrocarbons, Polymers)

Machinery (e.g. Trucks and vans, Vehicle Parts & Accesories)

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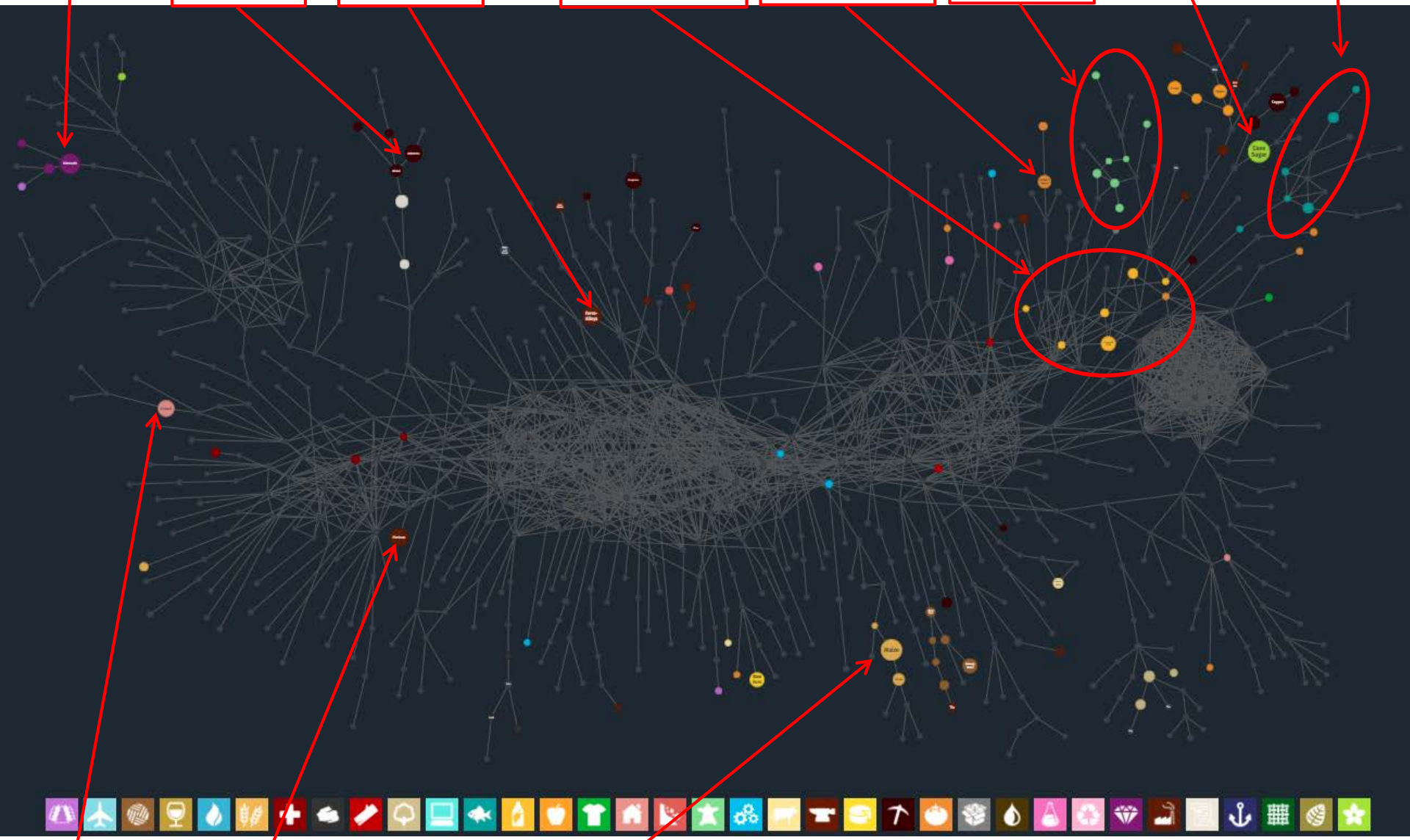
Product Space – South Africa (1975)



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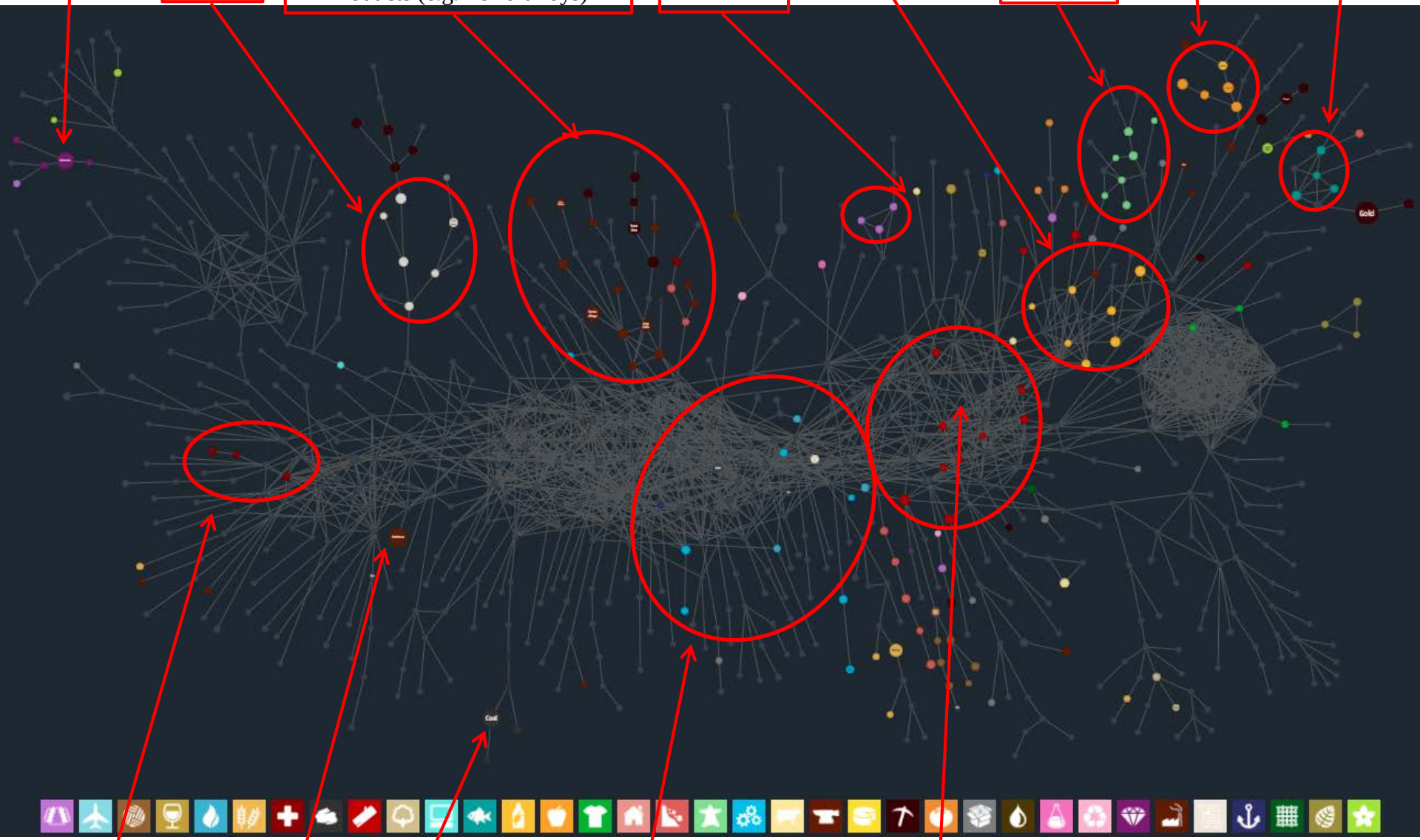
Product Space – South Africa (1994)



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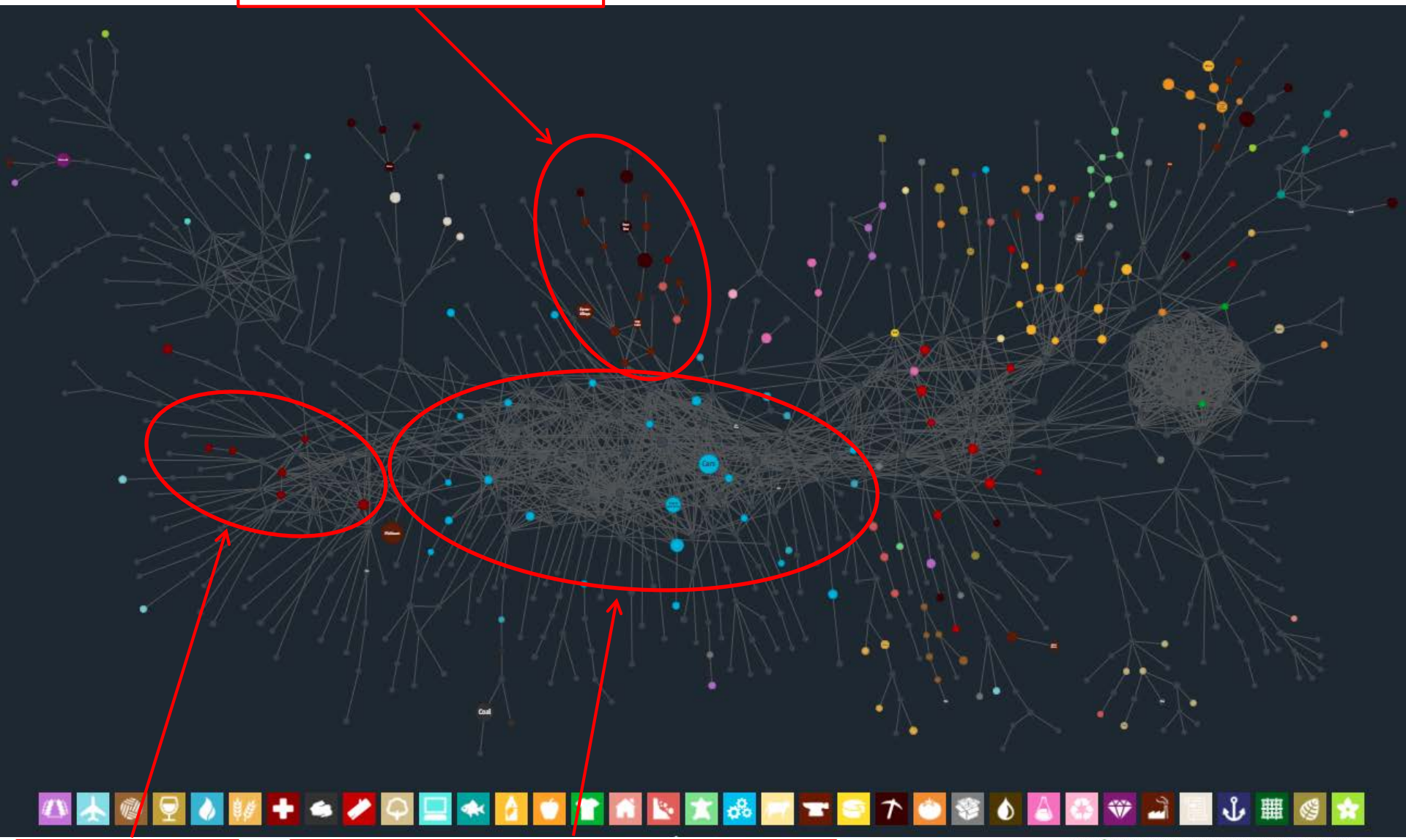
Product Space – South Africa (2015)



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The Product Space: Network Characteristics and what they tell us

The Product Space allows for the generation of a number of useful network measures…

Distance:

- This is a measure that quantifies the distance between the products that a country makes and each of the products that it does not make. How far each product is given a country's current export portfolio.
- Defined as the sum of the proximities connecting a new product p to all the products that country c is not currently exporting. Normalise distance by dividing it by the sum of proximities between all products and product p.
- If country c exports most of the products connected to product p, then the distance will be short, close to zero.
- Conversely, if country c exports few of the products related to product p, then the distance will be large, close to 1.
- Country-product level measure
- Formally this is written as:

$$d_{c,p} = \frac{\sum_{p}\left(1 - M_{c,p\prime}\right)\phi_{p,p\prime}}{\sum_{p\prime}\phi_{p,p\prime}}$$

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The Product Space: Network Characteristics and what they tell us

Opportunity Value:

- Provides a holistic measure of the opportunities implied by a country's position in the product space.
- Takes into account product complexity Index (PCI) – countries making relatively complex products grow faster.
- Countries not only differ in what they make but also in what their opportunities are. Some countries may be located near few, poorly connected and relatively simply products, whilst others may have a rich unexploited neighbourhood of highly connected or complex products.
- Quantifies the 'opportunity value' of a country's unexploited prospects by taking into account: 1) the level of complexity of the products that it is not currently producing, 2) weighted by how close these products are from a country's current export portfolio.
- Higher opportunity value implies being in the vicinity of more products and/or of products that are more complex.
- Also known as 'Complexity Outlook Index'
- Country level measure
- Formally this is written as:

$$Opportunity\ value_c = \sum_{p'} \frac{\phi_{p,p'}}{\sum_{p'} \phi_{p,p'}} \left(1 - M_{c,p'}\right) PCI_{p'} \left(1 - d_{c,p}\right) PCI_p$$

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Opportunity Gain:

- Use opportunity value to calculate the potential benefit to a country if it were to move to a particular new product - the opportunity gain that country c would obtain from making product p.
- Measured as the change in opportunity value that would come as a consequence of developing product p.
- Quantifies the contribution of a new product in terms of opening up doors to more and more complex products
- Also known as 'Complexity Outlook Gain'
- Country-product level measure
- Formally this is written as:

$$Opportunity\ gain_{c,p} = \sum_{p'} \left(1 - d_{c,p}\right)\left(1 - M_{c,p'}\right) PCI_{p'}$$

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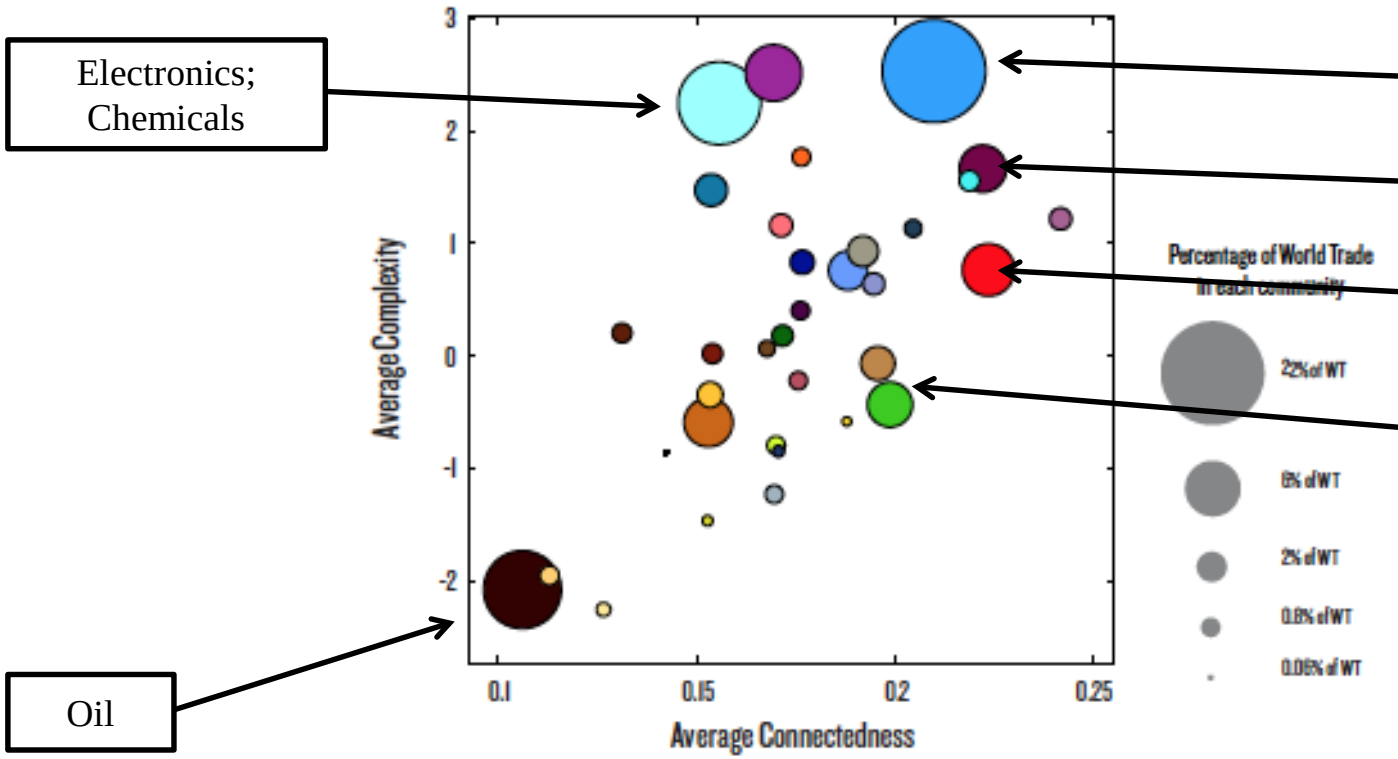

- Connectedness is a measure of how centrally located a community is in the product space (avg. proximity of a community's products to all other products)
- Positive relation between avg. complexity of products within a community and how centrally located those products are.

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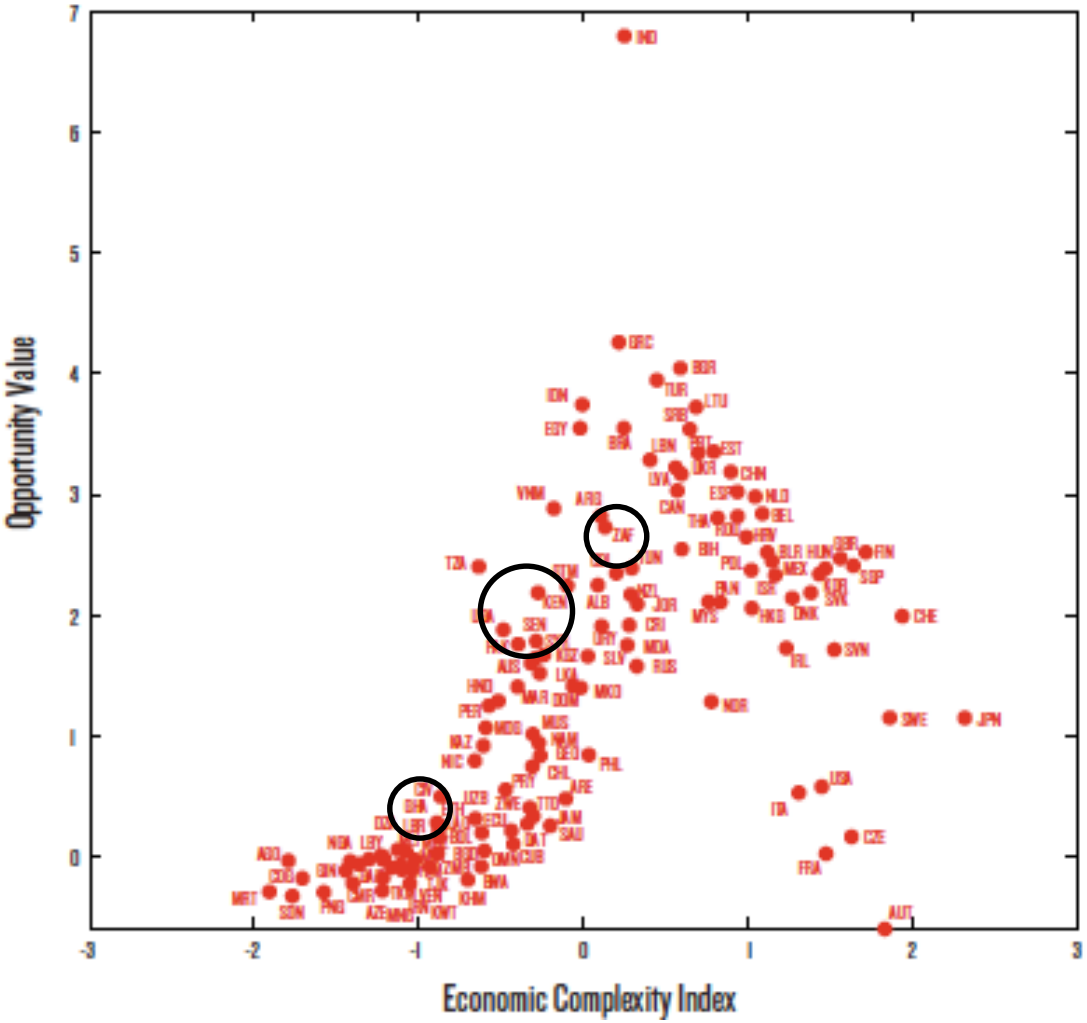
The Relevance of Economic Complexity



Inverse u-shape relationship between ECI and COI

- Countries with low levels of complexity tend to have few opportunities available – i.e. the products that they make have few opportunities available (i.e. Sudan; Angola)
- Complex economies tend to have few remaining opportunities because they already occupy a large portion of the better part of the PS (e.g. Japan; Sweden)
- Countries with intermediate level of complexity differ greatly in terms of opportunities (e.g. Jamaica, Chile, Saudia-Arabia located in sparse parts of PS and thus few opportunities versus Greece, Turkey and Brazil located in parts of the PS where opporuntities are many)
- Regression analysis shows that initial opportunity value predicts increased future complexity

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References: Product Space

The section discussing the product space is informed by the following sources:

- Hausmann, R., Hidalgo, C.A., Bustos, S., Coscia, M., Simoes, A. & Yildirim, M. 2014. The Atlas of Economic Complexity: Mapping Paths to Prosperity, Cambridge, Massachusetts: MIT Press. http://atlas.media.mit.edu/static/pdf/atlas/AtlasOfEconomicComplexity.pdf
- Hidalgo, C.A., Klinger, B., Barabasi, A. L. & Hausmann, R. 2007. The product space conditions the development of nations. *Science, New Series*, 317(5837), pp.482–487. Available at: http://www.jstor.org/stable/20037448.
- Hausmann, R. & Klinger, B., 2006. Structural transformation and patterns of comparative advantage in the product space, *CID Working Paper No. 128*, Harvard University. Available at: http://ksgnotes1.harvard.edu/Research/wpaper.nsf/rwp/RWP06-041.
- Hausmann, R. & Klinger, B., 2007. The structure of the product space and the evolution of comparative advantage, CID Working Paper No. 146, Harvard University. Available at: https://www.hks.harvard.edu/content/download/69250/1249810/version/1/file/146.pdf.

Also see the following websites:

- http://chidalgo.org/productspace/chnages.htm
- http://www.michelecoscia.com/?page_id=223
- http://statadaily.com/2010/08/28/productspaceparser/
- http://statadaily.com/category/product-space/
- http://www.cytoscape.org

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Thank you