Università di Torino

School of Management and Economics

Master's degree in Economics

Export and knowledge: an evaluation with an agent-based model

Tesi di Laurea in Simulation Models for Economics

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Academic Year

2014-2015

There is nothing which can better deserve our patronage than the promotion of science and literature. Knowledge is in every country the surest basis of public happiness. [1]

Non vi, sed ingenio et arte [2]

[1] George Washington
[2] latin motto

Acknowledgements

I express my gratitude to Professor Terna, who drove my efforts with wise advices and great helpfulness, his way to treat people is inspiring.
Thanks to my dad, he was everything to me and he will be always in my mind and in my heart; thanks to my beloved grandparents and uncles who follow me from the skies; thanks to my caring, adored aunt and to my dear mum, to all my family.
A special thanks to Luca Rubini, who gave incomparable support facing my last exams. Thanks to S.G.M, L.B., E.C., M.D., I.D., L.M., M.M., P.R., L.R., L.S., A.Z., who are in different ways part of my life and encouraged me to never give up.

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Introduction

On one side, I have been always fascinated by how nations that were fighting each other for years and years, trying to have a territorial predominance, once finally peace comes, they start to interact and have reciprocal advantages from international commerce. On the other side, during my economic studies I read many theories whose aim was to explain how nations interact and gain from international commerce. Most of the theories can describe pieces of economic mechanism, since the real world is a complex system of different trade-offs, and changes pushing away from equilibrium happen every day. Nevertheless with advent of computers able to make many calculations in few minutes, some theories strive for understanding complex dynamics which drive economics. In this work, I will describe classical economic theories about international exchange, about productivity and knowledge, and a new theory about economic complexity. An important part is dedicated to a model agent-based and to simulations deriving from this model. This model "pit against each other" classical comparative advantage theory and new theory of economic complexity focused on knowledge. To make the presentation clearer, I used a powerful free-ware program to draw diagrams: GeoGebra. It allows great freedom drawing diagrams starting from mathematical equations.

Chapter 1 briefly explains the source of inspiration of my work, that is the theory of economic complexity. Economic complexity is intended as a measure of the knowledge in a society that gets translated into the products it makes. In this part are mentioned paradigmatic examples of nations which had relevant growth during last decades. According to the theory, diversification is the main reason of growth and export, supported by the hint of the meaning of product space.

Chapter 2 describes most relevant classical economic theories about export and their evolutions during decades. The chapter begins with a brief historiography about export. Absolute advantage theory from Smith and comparative advantage theory from Ricardo are explained from a graphical and a mathematical point of view, with carefulness to hypotheses and providing short but substantial critic. After these cornerstones, the chapter illustrates other theories based on comparative advantage, such as the revealed comparative advantage theory from Balassa and the Heckscher-Ohlin theory, depicting resources endowment, factor prices theorem and Rybczynski theorem. This chapter concludes with a small digression about international classification of products and indexes in economics.

Chapter 3 refers about productivity, focusing on the main model about this topic, which is Solow-Swan model and the Solow residual. The following section illustrates the missing part of Solow-Swan model: endogenous theory. In this chapter finds place technical progress and tied human capital theory. Moreover, about human capital are enunciated three leading models.

Chapter 4 is the core of this work. It explains the meaning of the very recurring term "knowledge", depurating this term from the common misleadings. Even more important, it is expressed

the economic complexity theory with an explanation of what theory intends with "diversification" and "personbyte", followed by the mathematical background. Finally, is explained main critic regarding this theory.

Chapter 5 includes a comparison of helpful tools in policy analysis, with a brief classification and description. It points out the reasons why agent-based simulation should be considered the best tool in policy analysis. Beyond this part, is described the agent-based program: NetLogo. A brief motivation is provided, followed by an example about the flexibility and clarity of this program.

Chapter 6 is entirely dedicated to the description of the model created. Sections describe different levels of the model, with necessary additions of the relevant part of the code, starting from the basis till the final and definitive level used for the experiments in the following chapter. Those different levels have the aim to describe how is the work-in-progress of developing and the process of a detail-oriented job. Moreover, the aim to illustrate the validity of the simulation modeling comparative advantage theory and economic complexity theory, alluding to further extensions.

Chapter 7 is the realization of the model: experiments. These experiments are based on six scenarios created by the author, with the attempt to verify the validity of the two theories upon mentioned. Scenarios are tested in several experiments, accompanied by a description of waited results, effective results and the interface of NetLogo.

Chapter 1

Atlas of economic complexity

What makes economic growth? This is one of the most difficult and most debatable argument in Economics. All economists discussed about many theories for centuries and even nowadays is a topic without univocal answer. An emerging and very interesting theory, stated from Hausmann and his team, is emerging in the last years. Adam Smith was one of the first to theorize about economic growth. During Smith's age, the richest country in the world was the Netherlands and was about four times richer than the poorest country in the world. Today the poorest country in the world is Malawi, but if we multiply by four the actual income per capita of Malawi we have the income per capita of Haiti. Multiplying still by four we have the income per capita of Morocco, and still by four we have Poland. Multiplying by four income per capita of Poland, we have Canada. So today the richest countries in the world are about 250 times richer than the poorest countries. But is not just a problem of richness among countries, because within the same country, with same tax regime, same interest rate, the same exchange rate, we have differences in productivity per worker. We know that growth is a very recent phenomenon. If we look at incomes per capita from year 0 in figure 1.1, essentially there was no movement until this very last period.

But expanding the last 200 years there, it is possible to see that the explosion of growth is happening in a very differential way. Why there is a so hugh difference? An explanation could be productivity per worker, but what there is behind productivity per worker? There are many theories about this. Some theories would state availability of assets, factors of production like land, labor, capital and human capital. Anyway, the accumulation of this factors is not a secret of growth. The real puzzle is in productivity. If the US is thirty times richer than it was 200 years ago, it is not because it is producing thirty times more of the stuff that was producing 200 years ago. It's producing different kinds of goods that did not exist, with different kinds of techniques that did not exist, so the process of growth has made changing what you make and changing how you make. It is not having more stuff to make, but the change is in the things you make. It is the increase in productivity that underpins this growth process, in fact the increase in productivity is the process that allow to accumulate more capital. We can think that technology is pushing up economic growth, and technology is not essentially either question of tools or blueprints. You generate new equipment, new machines, new tools or new recipes, new ways of doing things. Why doesn't technology diffuses easily around the world? You can put a machine on a ship and send it around the world, it does not take long to ship something around the world. Or put a blueprint on the web, so that anywhere in the world who has Internet access can use it. The problem is that, in order to implement technology, there's a crucial ingredient. At some stage of production you need know-how. You need the ability of the brain to do things. The problem

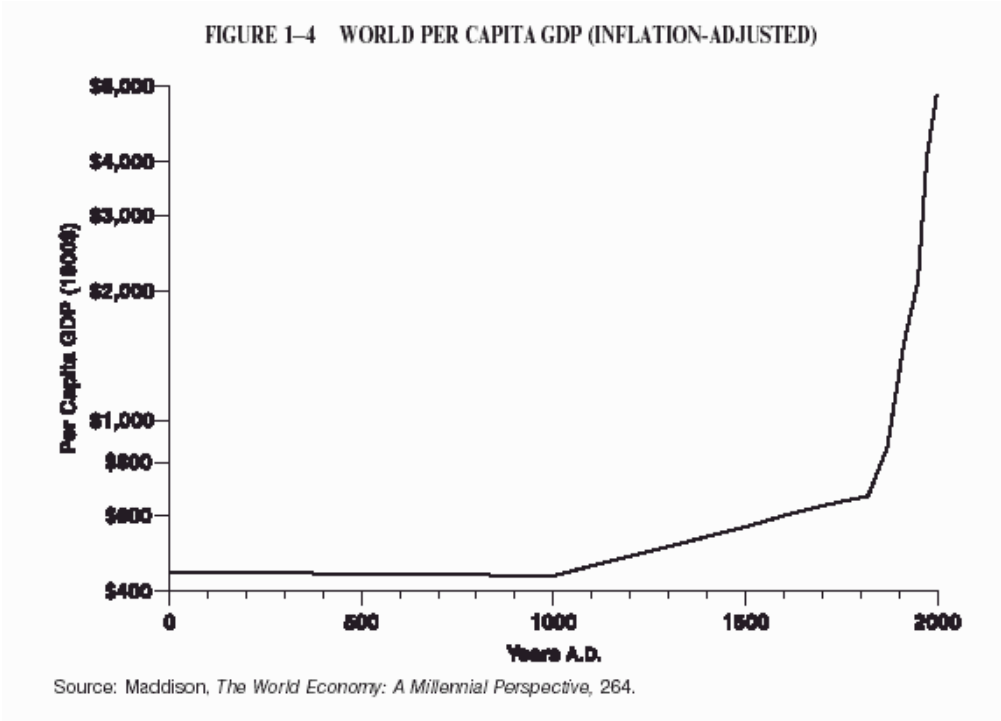


Figure 1.1: World economic growth from year 0

of today is not just how to do thing on your own, but how to do things in team, when people needs to have know-how to do different complementary things. According to Hausmann *et al.* (2011) (from now on HH), their hypothesis is that what slows down the process of development is the process of the fusion of this collected know-how. Imagine an Inuit, who must engage in food production, housing construction and transportation. Now imagine a normal boy, in front on a computer, with glasses and headset. He does not know how to make glasses, or headset, or a computer. If this boy was in Arctic, he would maybe find death because he does not know how to build a protection against cold, or how to fish or use dogs to transport. So, it is evident that this boy has much less know-how than the Inuit. But the society to which the normal boy belongs knows how to do more things than the society to which Inuit belongs. Not because the society of the normal boy is a bunch of geniuses but because in this society there are some people who knows how to make glasses, headsets, computers. It is the diffusion of know-how in the society, the division of know-how that underpins the capacity to do more things and more complicated. For example the 787 airplane is supposed to be built by Boing. This company has 165.000 workers, who makes less than 15% of the parts that go into the airplane. The parts have to come from all over the places (the 27% part of Boing Wikipedia (2016) comes from Italy) because you have to source the know-how of making these products in a long network. This does not mean that the secret of growth is to have very large companies. A symphony orchestra is a good example: every performer contributes a different bit of know-how to the whole, and you need the all set of the instruments to have the symphony. What is important is the network of know-how to which people are connected. And being connected to a network of many inputs that makes possible to mobilize all know-how and then generate productivity. It is possible to see better this framework using a game: Scrabble. In the game of Scrabble you have to make

words with given letters. But think of words as products and letters as bits of know-how. In order to make words you have to put letters in the same way you have to put instrument to have an orchestra. If you have one kind of letter, you are going to make one kind of word. But if you have three kinds of letters, (for example a, c and t), now you can make four kinds of words and three letter words (a, at, cat, act). With four letters you can make nine words and four letter words. With ten letters you can make 599 words! What is happening? Letter by letter, you have an increasing number of words, a better diversification of words you can create and longer words, that is more complex products. Now we can understand better the telltale of this process by looking at how many products countries are able to make and how hard it is to make these products. The most diversified country in the world is Germany and there are very few countries able to do what Germany produces. The poorest country in the world make few things and are things that every nation is able to produce. They make shorter words, while Germany makes long and complex words. HH invented a tool to develop an index with the attempt to measure how many letters a country has, that is how much productive capability a country has.

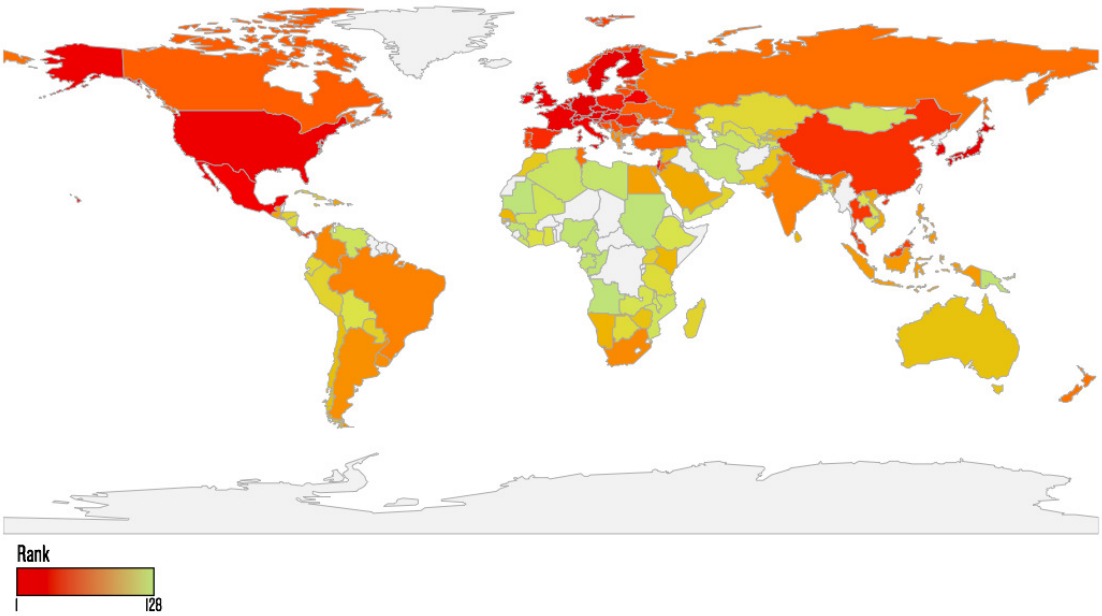


Figure 1.2: Map of the World colored according to ECI Ranking

Is diversification related to how much a country is rich? Yes, it is related. Looking at this figure 1.3 we see that there is a good relationship of how many letters a country have and how much rich this country is. But there is not a perfect relationship. Are data wrong? Taking India as example, why is India so poor given how much know-how it has? It is the reason why India is growing so fast, because it already has what it needs to be richer. The idea is that this metric of how much you know may drive where a country is going to and how rich is going to be. According to HH, the secret of growth is to get more letters and to express them into longer words and more complex words. Actually rises another problem. How do a country does that? For example, to make a watch we need a watchmaker, but if the country never made watches before there will be no watchmakers. More, if there is no watchmaker industry, how would some people want to become watchmakers? And even some people would become watchmakers, where are they going to learn from? The difficult is, how do a country coordinate the appearance of the

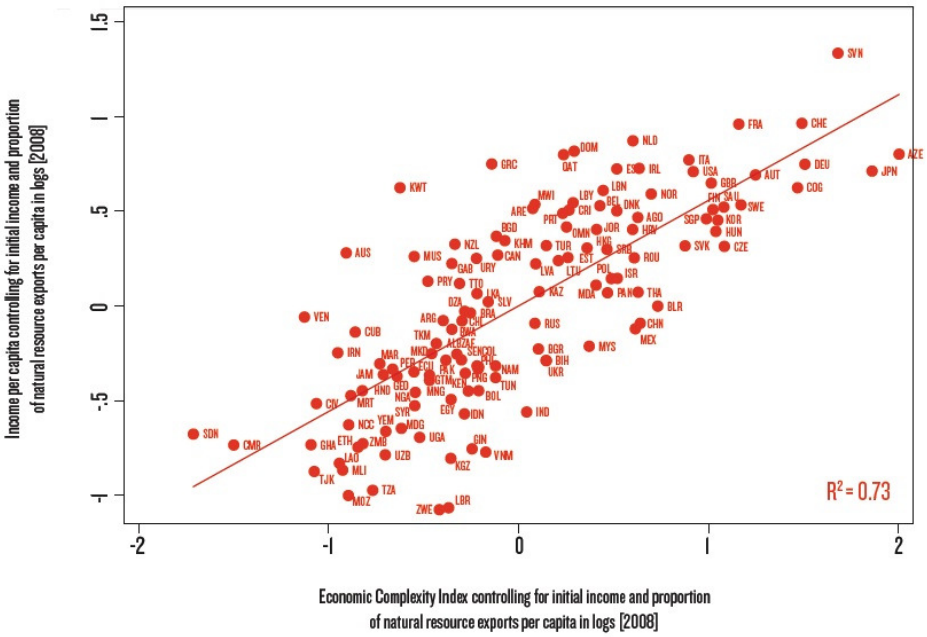


Figure 1.3: Economic complexity vs. income

letters with the demand for the letters in a industry that needs them? How a country coordinates the need of capabilities with the supply of capabilities? It is a "chicken and egg" problem, but an empirical solution appears looking at developing countries. We can use a metaphor where every product is like a tree in a forest. Trees are at a certain distance from each other. If trees are similar they are near each other, otherwise they are far away from each other inside the forest. The same concept is for products. HH were able to map this forest, and they called it "product space" 1.4. Every product is like a circle, and they are connected to other products that use similar skills and capabilities, cognitively speaking.

There are some dense part of the forest, for example machinery, construction material, transportations, chemical products, textile and others. HH affirms that products themselves in some ways put them where they are in the product space, according to the connection with other products. Oil products is big but is it disconnected, machinery is very much connected to other similar products. If a country is able to make a kind of machine, it easy to figure out how to produce other similar machines. This figure 1.5 helps to understand how much a sector is complex and how much is connected to other sectors. On the x-axis we see the average connectedness, on the y-axis the average complexity for each sector. Oil is very low connected and very low complex. On the opposite side, machinery and electronics are very complex and very connected.

This view re-describes the world and how we look to economy. In this description of the world, countries are collection of monkeys that live inside the forest. Monkeys are like firms, firms make products, products are trees. But how is it that monkeys move in this space and populate the forest? The story of Korea 1.6 is paradigmatic.

Other two paradigmatic nations, who tell us the difficulty to "populate" the product space are Ghana and Thailand. From 1962 Ghana invested more than Thailand in education, accumulating more years of schooling then Thailand. Ghana had the advantage that language in Ghana is English, that makes things easier. In 1962 their production was very similar, Ghana

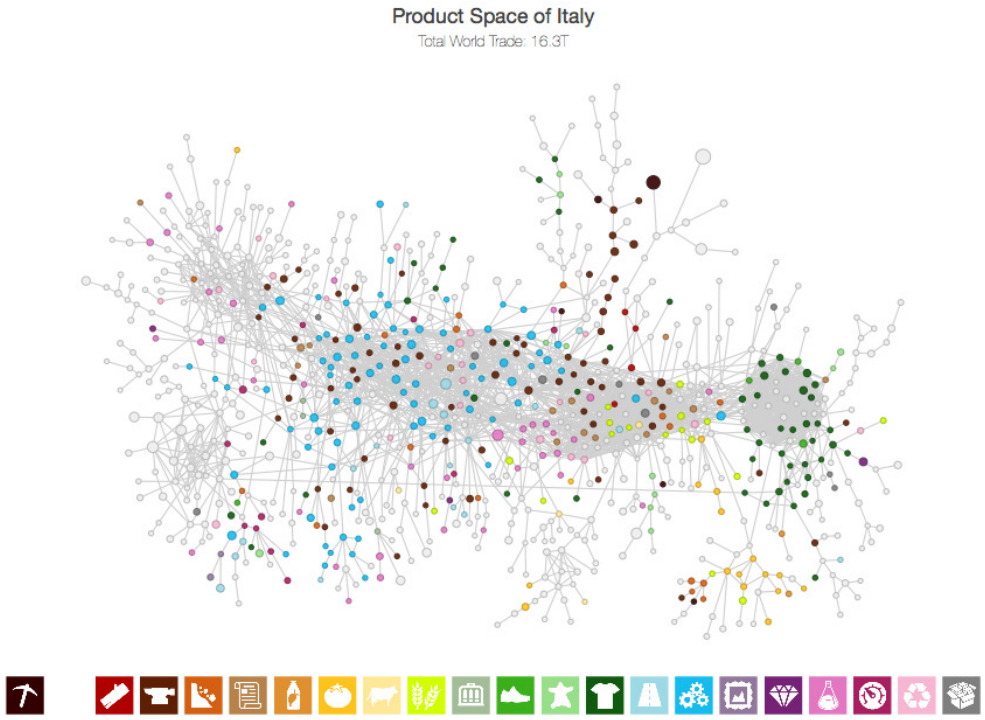


Figure 1.4: Italian product space - 2012

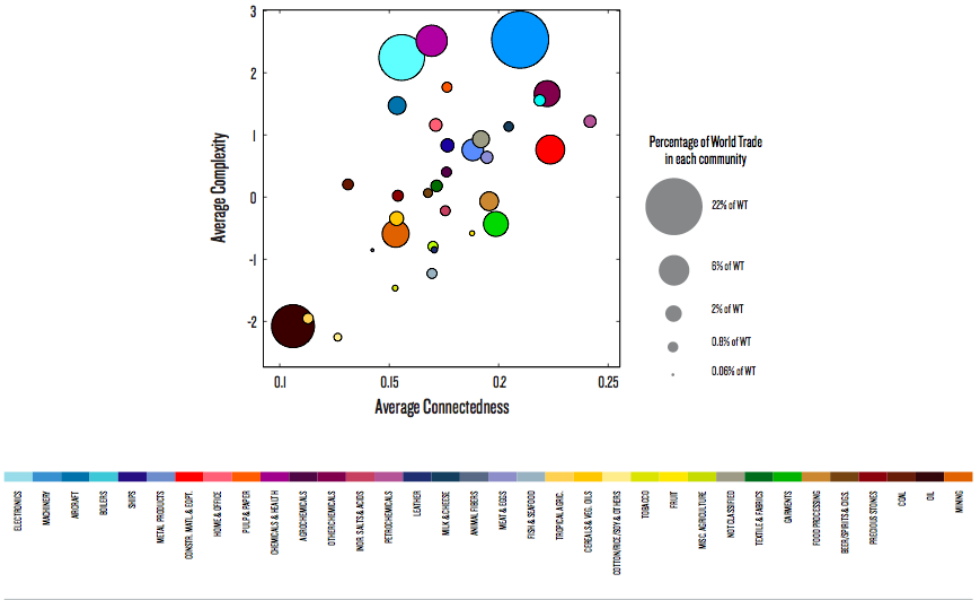
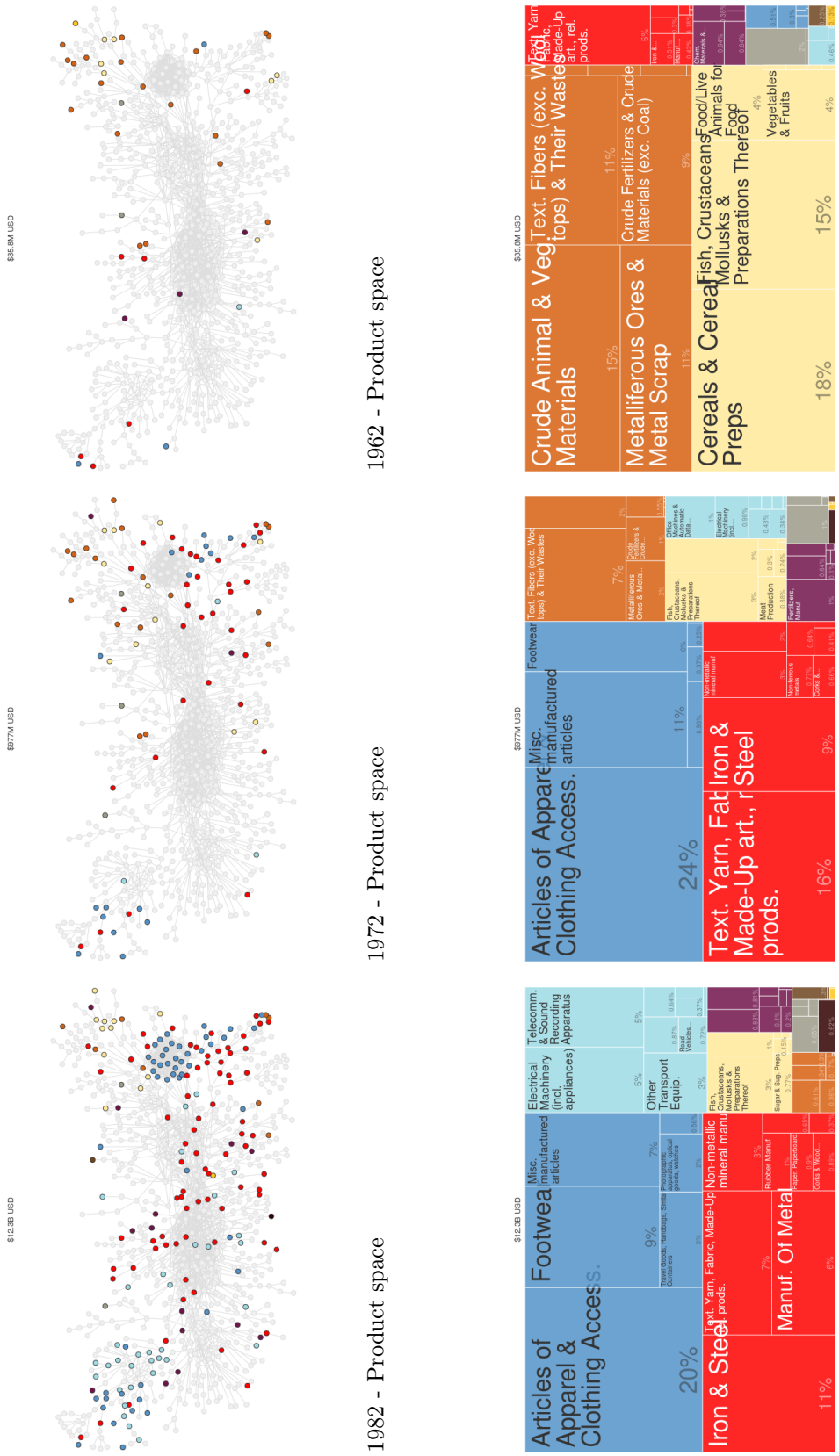


Figure 1.5: Community characteristics. Average complexity of the products in each community as a function of its connectedness. Bubble size is proportional to the community's participation in world trade.

Figure 1.6: Korea 1962 - 2012



1982 - Product space 1972 - Product space 1962 - Product space

1982 - Map 1972 - Map 1962 - Map

was producing mainly cocos, Thailand mainly rice, but essentially similar productive pattern and they were both poor. In 2010 Ghana diversified a little bit, Thailand completely transformed their production. Thailand introduced production of electronics, car, chemicals and many more products which were not produced before in this country. While income in 1962 was similar in both country, now Thailand's income is four and a half time higher then Ghana's income. Countries have heard many times that they should specialize in the areas of comparative advantage. According to HH, it is probably one of the most dangerous statement that has been ever said. In the process of growth, countries does not specialize. Countries diversify, they add and become good in producing more products. Italy is known in the world for the quality of its food. But if we look at the figure 1.7, we see that just a small part of italian total export regards food. Italy produces and exports many other products. Italy, like for example France, continues to produce quality food as many years ago, but evolved and becoming good to produce many other products. The process of diversification is not adding values to raw materials, it is about adding capabilities. It is about adding knowledge.

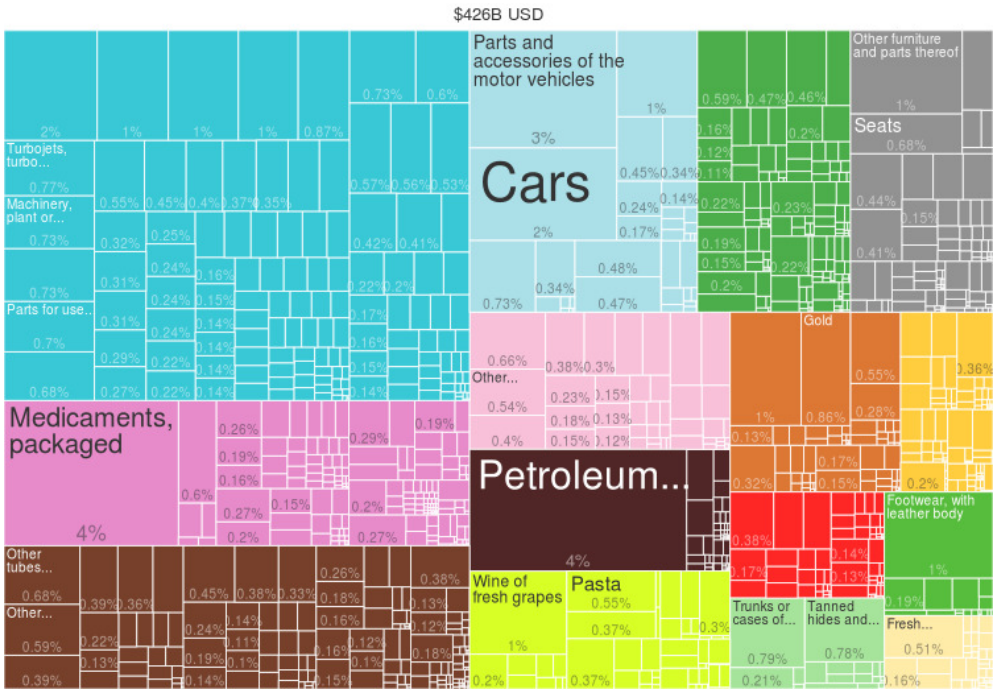


Figure 1.7: Italian export in 2010

Chapter 2

Export

2.1 Introduction

In the last twenty years everybody, at least once, has spoken about globalization. Somebody lauds it, somebody else hates it, but it is an unstoppable event. Globalization means an improvement in international trade, that is becoming more complex and interactive among countries. Globalization led to an increase in international trade, that is export and import of goods. The term *export* means, by definition, selling goods and services in a foreign country. Export is founded by the human desire to have something special, impossible to be found, created or produced in home country. After the II World War, international trade increased because of many reasons, especially the end of nationalist regimes in Europe and a long period of peace in the world's most advanced continents, Europe and North America. Peace and commerce are important factors leading to the development of a complex, economical network linking Europe with the rest of the world. We can say that World has become global after the communist downfall in Russia. New commercial agreements led to new trade route, giving to many countries opportunities to reach a higher welfare level for their citizens. Many people criticize globalization, because has increased the disparities of richness among countries. In this thesis maybe I might find a reason why globalization it is not the main factor. The story of countries is comparable to every man story, to everyone of us. Since everyone of us comes into the world with different endowment, different potential and different inclinations. It is our business to use what was given to us in the best way in order to satisfy our desires and reach our aims. It is the same for countries: some countries are rich of natural resources, other countries have less natural resources but citizens with very high education level. Countries can improve the own economical situation by exchanging resources connecting with others. But, especially in a globalized world a country, export is the key to increase a countries richness. Export is influenced by knowledge. According to my thesis, knowledge is the main factor for a successful export market, even if not in a direct way.

2.2 What is Export?

It means selling goods or services to another country, providing for demand which cannot be satisfied by foreign firms. For many countries, it is necessary to maintain an equilibrium in the commercial balance. As commercial balance (symbolised by NX) is understood the difference between monetary value of goods exported and imported in a certain period.

$$NX = export - import \tag{2.1}$$

If commercial balance has a surplus, it means that the level of export transactions is higher than level of import transactions. It is one of the main element balance of payment (BoP) in national account. Balance of payment includes goods, services, financial capital and financial transfers, all monetary transactions between countries and the rest of the world. In the past centuries, when nationalism was more diffused and countries tried to enrich themselves, protectionism (realized for example with mercantilism, a practice aiming to maximization of exportations and minimization of importation to accumulate gold with whom to finance frequent wars) was the driving economic policy for many countries. The "industrial revolution" was surely a breakout from a subsistence farming based economy, supported by two factors: on one side low fiscal pressure, on the other side protected and closed markets.

2.3 International commerce

2.3.1 History of export

Export during ancient age is considerable as trade over long distances, more than 'international', because exchange was among communities. The term 'international' should be applied for exchange among national state, which rose many centuries later. According to Stearns (2001) and Rawlinson (2001), there are records from the 19th century BC attesting the existence of an Assyrian merchant colony at Kanesh in Cappadocia. Moreover the Egyptians traded in the Red sea, importing spices from the "Land of Punt" (Horn of Africa) and from Arabia. Thanks to the domestication of camels, Arabian nomads took control of long distance trade in spices and silk from the Far East. Indian goods were brought in Arabian vessels to Aden and the "ships of Tarshish", a Tyrian fleet equipped at Ezion Geber (a city in the Gulf of Aqaba), made several trading voyages to the East bringing back gold, silver, ivory and precious stones. The greek Ptolemaic dynasty exploited trading opportunities with India prior to the Roman involvement. After the diplomatic travels of the Han dynasty chinese envoy Zhang Qian to Central Asia was established the Silk Road, with chinese goods making their way to India, Persia, and the Roman Empire, and vice versa. Then, with the establishment of Roman Egypt, the Romans initiated trade with India, and the goods from the East African trade were landed at one of the three main Roman ports, Arsinoe, Berenice or Myos Hormos. Proceding to Middle Age, Donkin (2003) affirms that at the eastern terminus of the Silk Road, the Tang Dynasty Chinese capital at Chang'an become a major metropolitan center for foreign trade, travel, and residence. Merchants arriving from India in the port city of Aden paid tribute in form of musk, camphor, ambergris and sandalwood to Ibn Ziyad, the sultan of Yemen. Meanwhile, in northern Europa the Hanseatic League secured trading privileges and market rights in England for goods from the League's trading cities, in 1157. Some centuries later, in order to settle new commercial route avoiding long terrestrial roads, Christopher Columbus convinced the spanish queen Isabella I of Castile to finance his project. After the colonization of America, starting from the beginning of seventeenth century, many companies were established to enhance international trade. These companies were chartered with the monopoly of trading with Southeast Asia, East Asia, and India. The most famous were:

- English East India Company, founded in 1600
- Dutch East India Company, founded in 1602
- Danish East India Company, founded in 1616
- Portuguese East India Company, founded in 1628

- French East India Company, founded in 1664
- Swedish East India Company, founded in 1731
- Austrian East India Company, founded in 1776

2.3.2 Mercantilists, Smith and Ricardo

In the seventh and eighteenth century some merchants, bankers and philosophers wrote pamphlets and papers about international commerce, sustaining that a nation had to export more than import to become richer and more powerful. The purpose of commercial surplus was to have an incoming flow of gold and precious metals. They evaluated the power of a nation based on the stock of precious metals owned, essential to maintain bigger armies and navy fleets, sustaining that a government had to strictly control importations and support exportations. To be more precise, they were supporters of an economic theory called mercantilism. But mercantilists had also less nationalistic reasons: more gold in a closed economy meant more economic activity, national production and occupation. It is important to notice that this kind of economy is a zero-sum game: if someone won, another one lost. We may think that this view is no more alive, but still in the twentieth century many countries tend to adopt these kinds of policy (Salvatore, 1993). Protectionism is not a good policy, even with a basic reasoning may seem obviously well-advised, it satisfies the most basic national interests. Protectionism gives an early advantage, considerable as a sort of *pyrrhic victory*. A sense of harmfulness of protectionism is satirically described by Bastiat (1845), in a petition addressed to French Parliament. (Complete text is Appendix .1)

> We are suffering from the ruinous competition of a rival who apparently works under conditions so far superior to our own for the production of light that he is flooding the domestic market with it at an incredibly low price; for the moment he appears, our sales cease, all the consumers turn to him, and a branch of French industry whose ramifications are innumerable is all at once reduced to complete stagnation. This rival, which is none other than the sun [...] We ask you to be so good as to pass a law requiring the closing of all windows, dormers, skylights, inside and outside shutters, curtains, casements, bull's-eyes, deadlights, and blinds - in short, all openings, holes, chinks, and fissures through which the light of the sun is wont to enter houses, to the detriment of the fair industries with which, we are proud to say, we have endowed the country, a country that cannot, without betraying ingratitude, abandon us today to so unequal a combat. Be good enough, honorable deputies, to take our request seriously, and do not reject it without at least hearing the reasons that we have to advance in its support. [...] To take another example: when a product - coal, iron, wheat, or textiles - comes to us from abroad, and when we can acquire it for less labour than if we produced it ourselves, the difference is a gratuitous gift that is conferred up on us. The size of this gift is proportionate to the extent of this difference. It is a quarter, a half, or three-quarters of the value of the product if the foreigner asks of us only three-quarters, one-half, or one-quarter as high a price. It is as complete as it can be when the donor, like the sun in providing us with light, asks nothing from us. The question, and we pose it formally, is whether what you desire for France is the benefit of consumption free of charge or the alleged advantages of onerous production. Make your choice, but be logical; for as long as you ban, as you do, foreign coal, iron, wheat, and textiles, in proportion as their price approaches

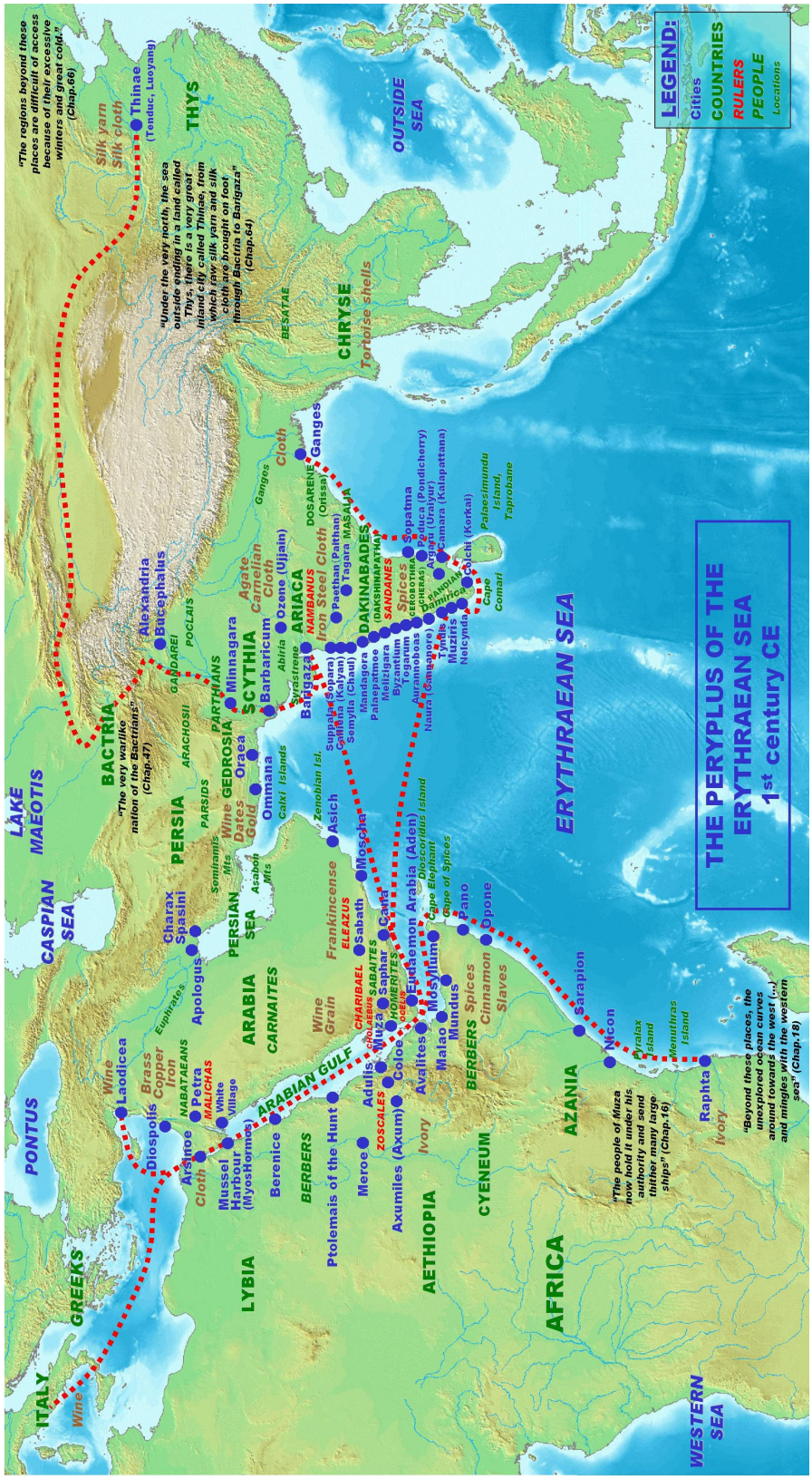


Figure 2.1: Roman trade with India according to the Periplus Maris Erythraei, 1st century AD

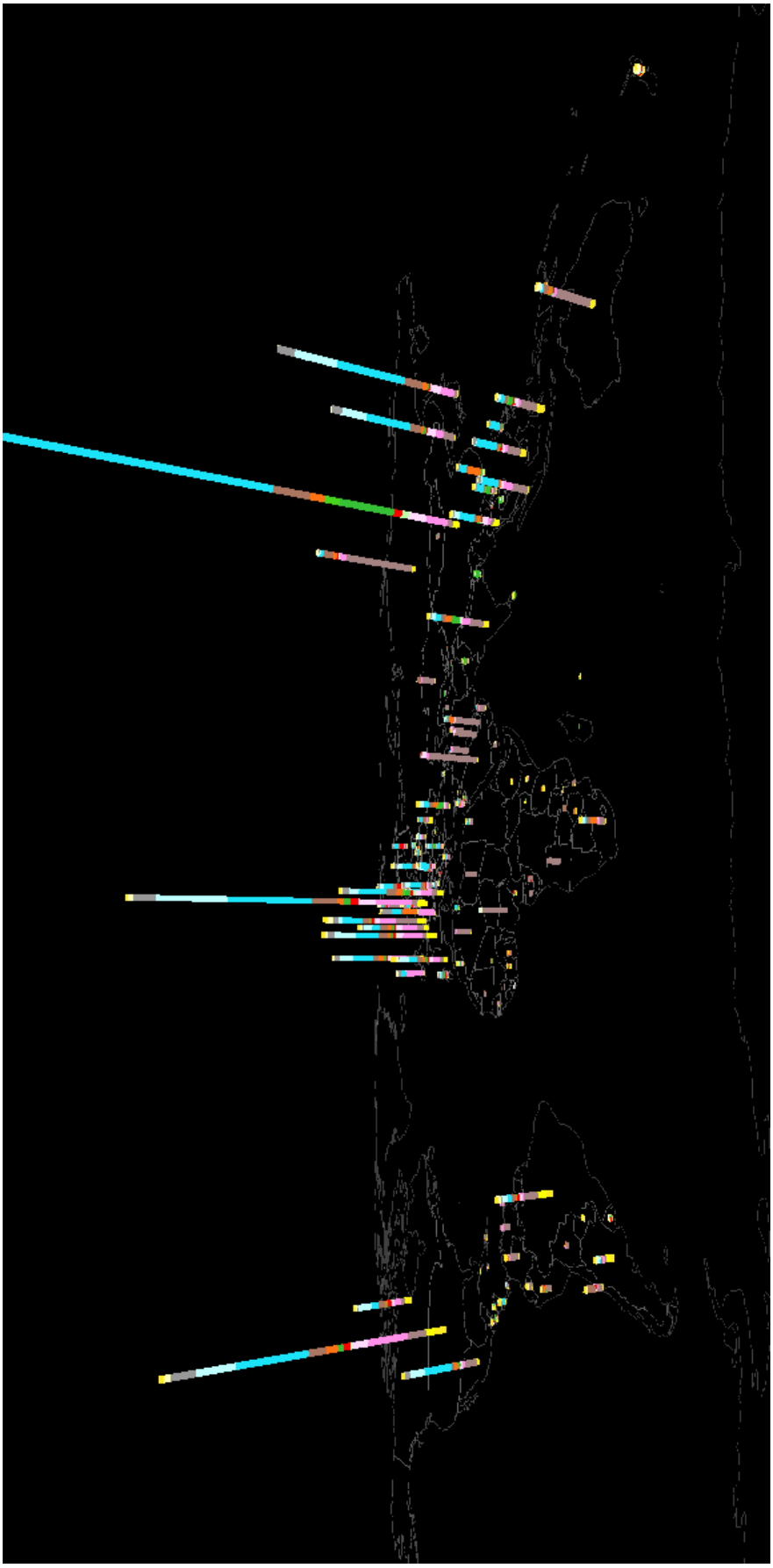


Figure 2.2: Global "panorama" of World exportations (from Atlas of Economics Complexity)

> zero, how inconsistent it would be to admit the light of the sun, whose price is zero all day long!

From a more economic point of view, it is possible to state that economic theory as structured scientific discipline born with "An Inquiry into the Nature and Causes of the Wealth of Nations" written by Adam Smith in 1776 (Salvatore, 2012). In his book Smith (1776) suggests, apart from other interesting arguments, his famous metaphor of the "invisible hand" and his concept of the division of labour. Smith wrote also about international commerce: his theory was a breakout respect to previous mercantilist theory. Two nations are willing to exchange goods if both could benefit from commerce. How is this possible? Smith states that two nations should base their trade on the "absolute advantage":

> The natural advantages which one country has over another, in producing particular commodities, are sometimes so great, that it is acknowledged by all the world to be in vain to struggle with them. By means of glasses, hot-beds, and hot-walls, very good grapes can be raised in Scotland, and very good wine, too, can be made of them, at about thirty times the expense for which at least equally good can be brought from foreign countries. Would it be a reasonable law to prohibit the importation of all foreign wines, merely to encourage the making of claret and Burgundy in Scotland? But if there would be a manifest absurdity in turning towards any employment thirty times more of the capital and industry of the country than would be necessary to purchase from foreign countries an equal quantity of the commodities wanted, there must be an absurdity, though not altogether so glaring, yet exactly of the same kind, in turning towards any such employment a thirtieth, or even a three hundredth part more of either. Whether the advantages which one country has over another be natural or acquired, is in this respect of no consequence. As long as the one country has those advantages, and the other wants them, it will always be more advantageous for the latter rather to buy of the former than to make. It is an acquired advantage only, which one artificer has over his neighbor, who exercises another trade; and yet they both find it more advantageous to buy of one another, than to make what does not belong to their particular trades.

Smith does not agree with mercantilists and their protectionism. He is against closed economy promoted by mercantilists, sustaining that nations may take reciprocal advantage from trade, siding him against the win-lose game implicitly endorsed people who was nearer to the power. He hardly disapproves mercantilistic kind of economy, considering it not just without benefit, but also absurd.

> Nothing can be more absurd than this whole doctrine of the balance of trade, upon which, not only these restraints, but almost all the other regulations of commerce, are founded. When two places trade with one another, this doctrine supposes that, if the balance be even, neither of them either loses or gains; but if it leans in any degree to one side, that one of them loses, and the other gains, in proportion to its declension from the exact equilibrium. Both suppositions are false. A trade, which is forced by means of bounties and monopolies, may be, and commonly is, disadvantageous to the country in whose favour it is meant to be established, as I shall endeavour to show hereafter. But that trade which, without force or constraint, is naturally and regularly carried on between any two places, is always advantageous, though not always equally so, to both. By advantage or gain, I understand, not the increase of the quantity of gold and silver, but that of the exchangeable value of the annual

> produce of the land and labour of the country, or the increase of the annual revenue of its inhabitants. If the balance be even, and if the trade between the two places consist altogether in the exchange of their native commodities, they will, upon most occasions, not only both gain, but they will gain equally, or very nearly equally; each will, in this case, afford a market for a part of the surplus produce of the other; each will replace a capital which had been employed in raising and preparing for the market this part of the surplus produce of the other, and which had been distributed among, and given revenue and maintenance to, a certain number of its inhabitants. [...] If their trade should be of such a nature, that one of them exported to the other nothing but native commodities, while the returns of that other consisted altogether in foreign goods; the balance, in this case, would still be supposed even, commodities being paid for with commodities. They would, in this case too, both gain, but they would not gain equally; and the inhabitants of the country which exported nothing but native commodities, would derive the greatest revenue from the trade.

To make a clear example, we could think about two countries as Canada and Nicaragua. The canadian weather conditions are facilitating to produce corn, while the production of bananas won't be successful due to the climatic circumstances. In case of Nicaragua it works vice versa: the warm climate offers best condition for the cultivation of bananas, but not for a rewarding production of corn. Canada has an "absolute advantage" in producing corn and Nicaragua in producing bananas. According to Smith's theory, Canada and Nicaragua would have more benefits specializing in the production of the good in which they have an absolute advantage and exchanging the surplus of production with the other country. The consequence is an higher level of production and consumption of both goods, and profit of both nations gained on the strength of exchange. While mercantilists stated that a country could "win" just with the "loss" of the other country, Smith, as many other classic economists later, opposed the idea of *lasseiz-faire*, which means a minimum intervention of governments, with its constraints, in the market (Salvatore, 2012).

An evolution of the Smith's theory was the one of David Ricardo, written in 1817. Ricardo theorized a model called "Theory of comparative advantage", formalizing that a country has a comparative advantage respect to another country in producing a good if the cost of this good, compared to the cost of production of other goods in the first country, is lower than cost of production in the second country, compared to cost of production of other goods in the second country. The comparative advantage is present in the good which the absolute disadvantage is lower. Although an absolute disadvantage in both goods, is the profit in commerce still remaining even if a nation has just a comparative advantage? Ricardo's answer is positive.

2.3.3 Absolute advantage and comparative advantage: two examples

We see now a numeric example of absolute advantage and comparative advantage. On one hand, in the USA one hour of work produces 6 bushels of corn but just one bushel in United Kingdom. On the other hand, in United Kingdom 1 hour of work produces 5 yards of textile while in USA 4 yards.

	USA	United Kingdom
Corn (bushel/hour-man)	6	1
Textile (yards/hour-man)	4	5

With this situation, USA has an absolute advantage in production of corn while United Kingdom has an absolute advantage in production of textile. Introducing international commerce,

USA should specialize its production and making more corn, while UK should produce more textile, shifting workers from production characterized by disadvantage to production characterized by advantage. If USA exchange 6 bushels of corn with 6 yards of UK textile, USA would have a benefit of 2 textile, because with only national commerce the exchange would be 6 bushels of corn for 4 yards of textile. At the same time, UK would need 6 hours of work to produce 6 bushels of corn, but these 6 hour of work could be relocated in producing 30 yards of textile. Now, if UK exchange 6 yards of textile with 6 bushels of corn, UK can save 5 hour of work (30 yards produced - 6 yards exported to USA). It is clear that both nations have a benefit with exchange. UK have a bigger benefit, but is not so important how big is the benefit at this level, it is important that both nations have a benefit. Analyzing the example of comparative advantage, we will see that absolute advantage is a particular case of comparative advantage. Let take again USA and UK. Now UK has an absolute disadvantage in producing both goods, because UK produces 2 yards/hour-man of textile instead of 5 (level of corn production does not change):

	USA	United Kingdom
Corn (bushel/hour-man)	6	1
Textile (yards/hour-man)	4	2

Because productivity of work for UK is half respect to USA producing textile, while producing corn the productivity of UK is one-sixth respect to USA, the theory of comparative advantage states that United Kingdom has a comparative advantage in producing textile. USA has an absolute advantage higher in corn respect to textile, it is possible to say that USA has a comparative advantage in the production of corn. Stated this, there is still possibility for a reciprocal profitable exchange. Little precondition: USA is indifferent respect to commerce if it can exchange 4 textile for 6 corn, because this quantity can be exchanged inside. UK is indifferent in exchanging 2 textile every 1 unit of corn. Suppose that USA and UK would exchange 6 units of corn for 6 units of textiles: USA would have a benefit of 2 yards of textile respect to not trading. UK has a benefit importing 6 bushel of corn and moving production from corn to textile: UK can now produce 12 yards of textile and trade 6 yards of textile for 6 bushel of corn. Notice that the trade of 6 bushel of corn for 6 yards of textile is not the only exchange with profit for both nations. From USA point of view, every exchange that give more than 4 yards of textile is profitable. From UK point of view, every exchange is profitable if less than 12 yards of textile are traded for 6 bushel of corn.

2.3.4 Hypotheses of comparative advantage

Ricardo based the theory of comparative advantage on some hypotheses:

- two nations and two goods
- free trade - no cost of transactions
- perfect occupational mobility inside nations - no occupational mobility between nations
- fixed production cost
- no costs of transport
- no technological progress
- labor theory of value

All hypotheses, except one, are correct but also easily modifiable and removable. Salvatore states that the one not correct is the last one: labor theory of value. According to this theory, labor is the only production factor and it is homogeneous. These two assumptions are not correct, because, first, labor cannot be considered as the only production factor but capital is an important production factor. Second, labor is not homogeneous because it has many level of productivity, wage and knowledge. The problem about labor theory of value was passed by Haberler *et al.* (1936) with the opportunity cost theory. This theory states that the cost of a good is given by the value of a second good which must be given up to make available resources needed to produce an additional unit of the first good. In other words, is the "loss of potential gain from other alternatives when one alternative is chosen".[1] In the comparative advantage theory, it means that a country with lower opportunity cost in producing a good has a comparative advantage about that good. Using the data of previous example, US must give up 2/3 of textile to produce an additional unit of corn, so that the opportunity cost to produce an additional unit of corn is 2/3 unit of textile. In UK is 1/2. With this situation, the opportunity cost of producing corn is lower in US than in UK, and US has a comparative advantage in production of corn respect to UK. It is the same previous result, but opportunity cost theory gives a more powerful basis than labor theory of value. Opportunity costs can be shown using the "production-possibility frontier": it is a curve representing alternative combinations of two goods that a nation can produce using all its resources, given the best available technology. A point on the curve represents a combination of the production for the two goods. It defines also productive efficiency in the context of a specific production set: a point on the frontier indicates efficient use of the available inputs, while a point below the curve indicates inefficiency. A point over the curve is a not possible combination. The grade of the curve indicates that a nation must give up a part of its production of a good to produce more of the other good. In our previous US-UK case, in order to produce more corn, each nation has to give up production of textile. Opportunity costs can be constant, increasing or decreasing. If they are constant, (see Figure 2.3) it means that:

- resources or productive factors are perfect substitutes, or are used in fixed proportion for both productions
- all unit of a productive factor are homogeneous (or have the same quality)

It means that for all combinations of production must be given up the same amount of a resources to produce an additional unit of the other good. The amount given up is called "marginal rate of transformation", and, graphically speaking, is (absolute value of) the inclination of the production possibility frontier. On the example of figure 2.3, inclination of US frontier is 12/18 = 2/3, constant. For UK, (see figure 2.4) marginal rate of transformation is 12/6 = 2. In our US-UK case, in absence of international trade, PPF represents also the "consumption possibility frontier", that is a nation can consume just the goods which produce. US can decide to consume a combination of corn and textile (9 units of corn and 6 units of textile, point A on figure 2.5). UK can choose a different combination (4 units of corn and 4 units of textile, point D on figure 2.6). Suppose now that the option of international trade is back available. In this case, US would specialize in production of corn (the good thanks to which US have comparative advantage) and would produce in B point, 18 units corn and 0 unit of textile. On the opposite side of the Atlantic Ocean, UK would produce just the good which has comparative advantage, that is textile. So, UK produces now 0 unit of corn and 12 units of textile. Then, if US exchanges 7 units of corn for 7 units of textile with UK, the situation is that US can now consume the combination of 11 units of corn and 7 units of textile, while UK can consume the combination of 5 units of textile and 7

[1] Jewell and Abate (2001)

units of corn. As visible in figure 2.5, thanks to international trade, respect to closed market, US improves its consumption of 2 units of corn and 1 unit of textile, UK improves its consumption of 3 units of corn and 1 unit of textile. The new increased level of production makes possible a higher consumption level, while specialization of production makes possible new increased level of production. With closed market US and UK produce 13 units of corn and 10 units of textile; with international trade and specialization US and UK produce 18 units of corn and 12 units of textile, with a production boost of 5 units of corn and 2 units of textile. This theory looks plausible from a theoretical point of view, but there are economists who gave reasons and proved it from an empirical point of view. MacDougall (1951), using productivity labour data and exports data about United Kingdom and Unites States, proved that the comparative advantage model gave reasonably good results in term of explanation for trade structure. Industries where labour productivity was higher in United states respect to United Kingdom were those in which higher was the relation between american exports and british exports. Even other economists as Stern (1962), Balassa (1963) and Golub (1994) confirmed what explained by Macdougall. Nevertheless it is important to remind every nation has different opportunity costs, which are not realistic but help to understand the mechanism.

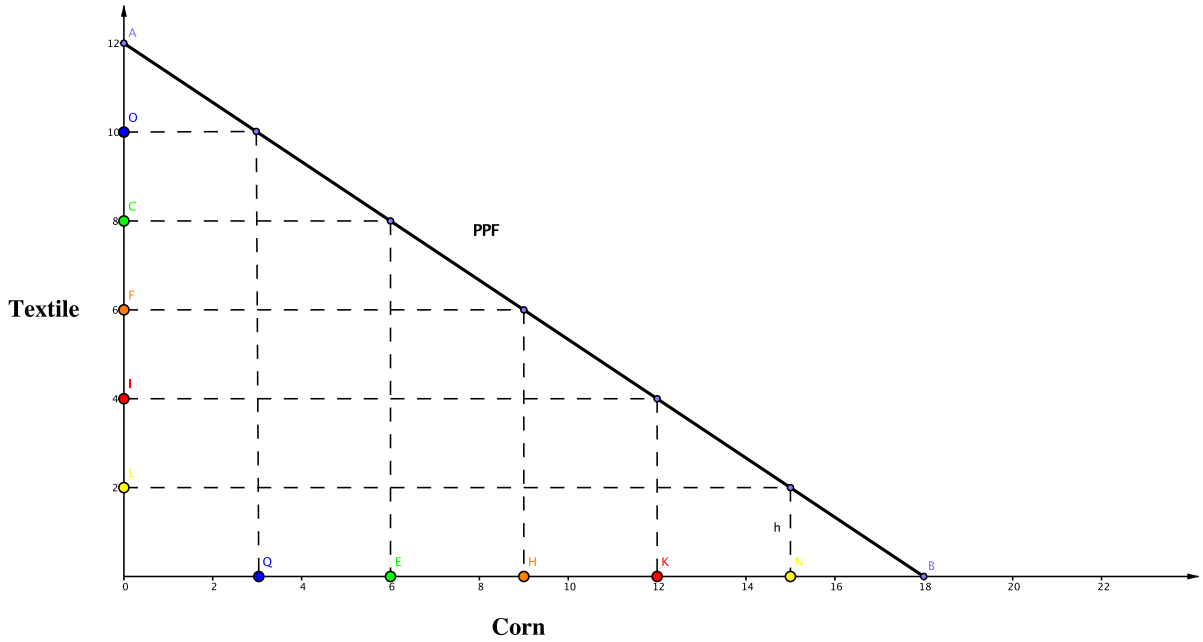


Figure 2.3: Production possibility frontier with constant opportunity costs - closed market (US case)

2.3.5 Production possibilities frontier with increasing costs

Opportunity costs increasing means that a nation must give up more and more quantity of a good to let free resources to produce an additional unit of another good. This kind of costs leads to a frontier not linear but concave with respect to the origin. In figure 2.7, the country must give up growing quantity of good X to produce two more units of good Y. The quantity that a country has to give up is called MRT (Marginal Rate of transformation). MRT is the amount of good Y that a country must give up to produce every additional unit of good X (MRT of X

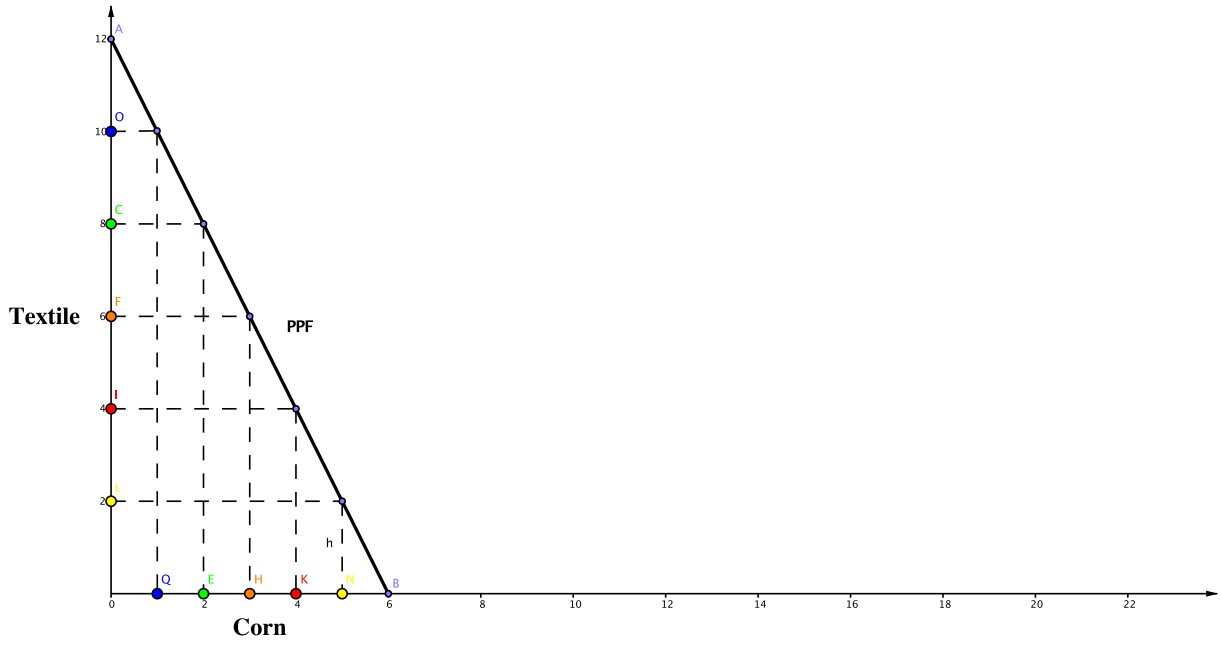


Figure 2.4: Production possibility frontier with constant opportunity costs - closed market (UK case)

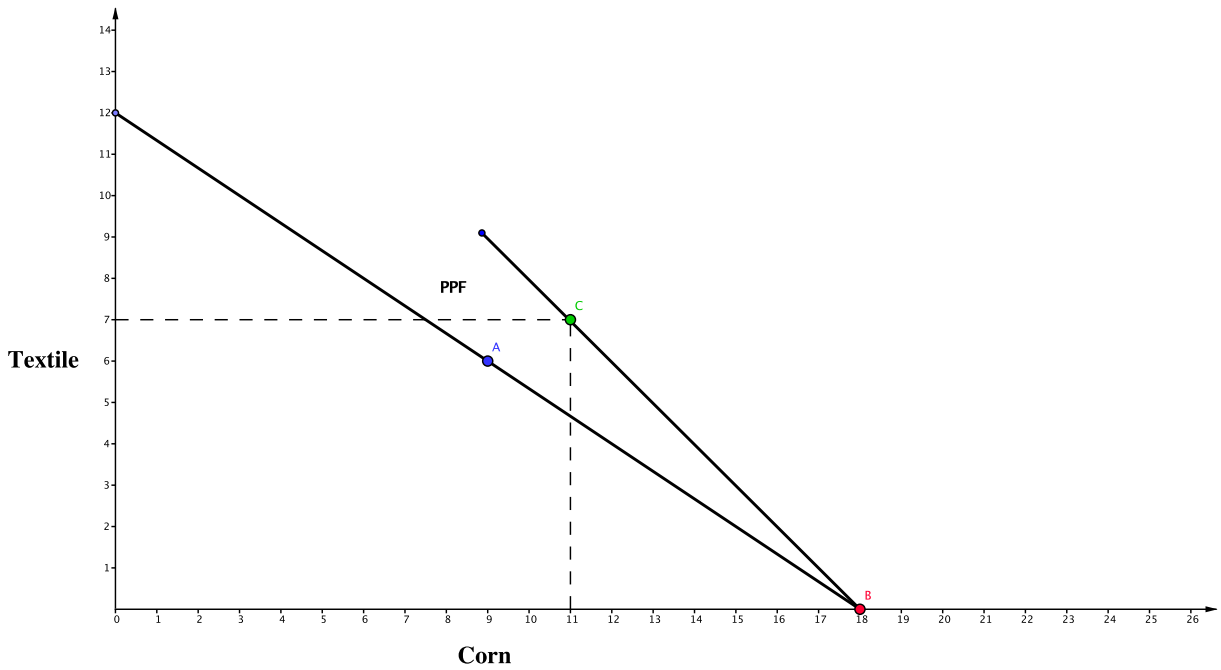


Figure 2.5: Production possibility frontier with constant opportunity costs - with trade (US case)

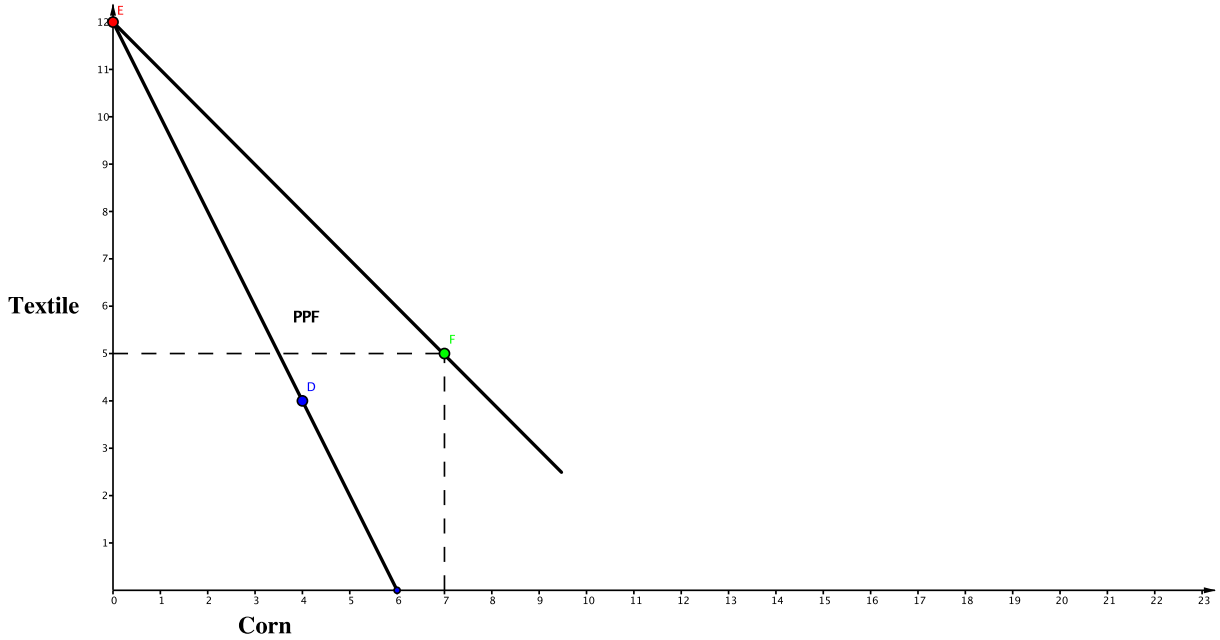


Figure 2.6: Production possibility frontier with constant opportunity costs - with trade (UK case)

in terms of Y). It is represented by the slope of the production frontier calculated at the point where production is. For istance, if MRT is 1/4 it means that the country must give up 1/4 unit of good Y to produce 1 unit more of good X. If MRT is equal to 1, it means that the country must give up 1 unit of good Y to produce 1 unit more of good X. This value is different along the production frontier, and it is the signal that there are growing opportunity costs. But why are there growing opportunity costs? Because two kinds of reasons:

- resources and productive factors are not homogeneous (not every unit is equal to the others or have the same quality)
- resources and productive factors are not used with the same proportion or intensity in the production of all goods

2.3.6 Revealed comparative advantage

Another economist, Balassa (1965), tried to explain the degree of trade specialization of a country with the index of revealed comparative advantage. Basically, it aims to calculate the relative advantage or disadvantage of a certain country in a certain class of goods or services, using data provided by trade flows. The formula to calculate revealed comparative advantage is the following:

$$RCA = \frac{(Eij/Eit)}{(Enj/Ent)}$$

where:

- E represents export

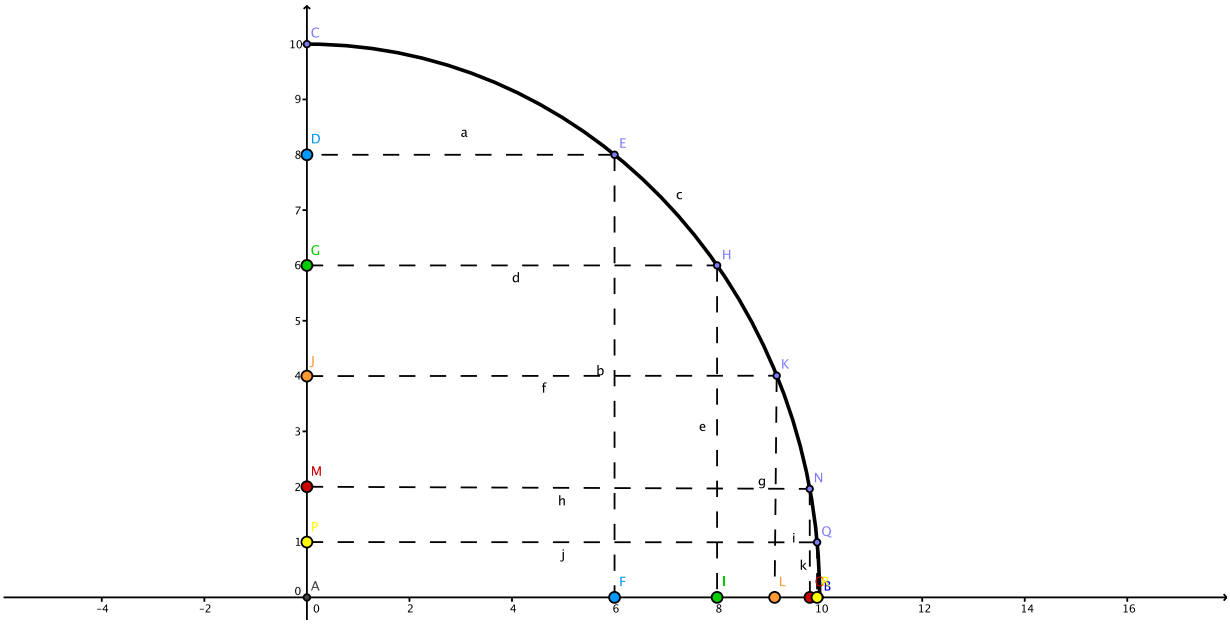


Figure 2.7: Production possibility frontier with increasing opportunity costs

- i represents country index
- n represents set of countries
- j represents commodity index
- t represents set of commodities

If RCAij > 1 indicates country i has a comparative advantage in production of j. If RCA < 1 indicates country i has a comparative disadvantage in production of j. The smaller the index, the greater the disadvantage and vice versa in case of index greater than 1. The Balassa index aim is to calculate from numerical point of view comparative advantage. According to Bowen (1983), even if this index has been largely used to come close countries' sectorial specialization, it suffers vulnerability, both theoretical and empirical. From theoretical point, ricardian comparative advantage is based on the intrinsic (ex-ante) nature of the country in being relatively more efficient in the production of a certain good. Balassa index fails in fitting this idea since it is based on the actual (ex-post) realization of bilateral sector's trade flows, mixing up exporter with importer and sector specific factors affecting trade. From empirical point, according to Leromain and Orefice (2013), Balassa's index does not have a stable distribution over time and it provides poor ordinal ranking property.

2.3.7 The attempt of building a palace before foundations

The theory of Ricardo is well-known and accepted by economic world, already convincing from when it was made public in early nineteenth century. But history is full of wonderful and arcane mistakes, and in the small this is one of those. Suggested by this article from Rothbard (2012), let me do a small digression about Ricardo and his theory. Researches by Thweatt (1976) stress the evidence that Ricardo is famous for the comparative advantage theory even if he was not

a big supporter of this theory. Thweatt sustains that Ricardo included the theory in is book persuaded by James Mill, and in his book *Commerce Defended* he explained better than Ricardo comparative advantage theory. Moreover, Ricardo gave little place in his book for previous theory, just few paragraphs. Anyway comparative advantage theory is a milestone in economic theory, always actual. But till the third decade of twentieth century, more than one hundred years later, Ricardo's theory was like a palace without foundations. These foundations were provided by two swedish economists: Heckscher and Ohlin. Eli Heckscher (1919) wrote an article with the title "The effect of foreign trade on the distribution of income", which was elaborated and integrated by Bertil Ohlin (1967), earlier Heckscher's student, in the book "Interregional and international trade". Heckscher-Ohlin (from now on H-O) theory can be explained with two basic theorem, the H-O theorem and the *factor prices equalization* theorem. The H-O theorem states that:

> a country exports goods whose production uses the productive factor relatively more abundant and less expensive in the country and imports goods whose production needs productive factor less abundant and more expensive.

If a country is relatively abundant of capitals, it exports *capital-intensive* goods and imports *labour-intensive* goods. The H-O theorem is also known as the theory of factors proportions. It means that a country specializes itself in producing goods which needs the productive factor relatively more abundant and less expensive. If a country is capital-abundant (capital is more abundant than labour), this country will export the capital-intensive good, while will import the labor-intensive good. For this reason H-O theorem explains comparative advantage, affirming that difference about relative abundance and relative prices of factors causes international trade. The factor prices equalization theorem states that international trade drives to the equilibrium of relative and absolute remunerations of homogeneous factors among countries. Supposing no trade, relative price for good X (labour-intensive) is lower in country 1 respect to country 2, because relative wage in country 1 is lower than in country 2. Trade drives to specialization in production of good X, reducing production of good Y (capital-intensive), but leading to an increase of labour's demand and consequently an increase in wage. Reducing production of good Y leads to a fall of interest rate. Opposite situation for country 2, which specializes its production of good Y, leading to a raise of interest rate and slowing wage. It is now clear how international trade drives to reduce differences between wage and interest rate among countries. The H-O theorem is based on some simplifying hypotheses, which do not subtract importance and truthfulness to the theorem. These hypotheses are:

1. two countries, two goods and two productive factors (typically labor and capital)
2. same technology in both countries
3. one good is labour-intensive, while the other good is capital-intensive
4. both goods are produced with constant returns to scale
5. incomplete specialization for production in both countries
6. preferences are the same in both countries
7. perfect competition for goods and productive factors in both countries
8. perfect mobility of productive factors inside each country, but no mobility of productive factors between countries
9. no costs of transportation and duties

10. full use of resources in both countries

11. balance in trade between countries

The majority of above hypotheses are quite straightforward, but some explanations are necessary:

- hypothesis 4 means that increasing labour and capital quantity used for the production of a good, the level of production increase proportionally by the same amount

- hypothesis 5 means that both countries produce both goods; in other words, neither of the two country is very small, but they have similar dimension

- hypothesis 8 means that capital and labour are able to move from sectors with lower remunerations to sectors with higher remunerations, until an equilibrium between remunerations of capital and labour

2.3.8 Main critics to comparative advantages

Samuelson (as we can read in Kennedy (2014)) described comparative advantage theory with a brilliant sentence: "If theories like girls, could win beauty contests, comparative advantage would certainly rate high in that it is an elegantly logical structure". Nevertheless, this theory has been hardly criticized because its simplistic assumptions. Main critics are owed to:

- unrealistic presence of only two goods

- constant costs, while in the real world firms face increasing returns to scale and economies of scale

- perfect competition

- absence of trade barriers

- unrealistic assumption of labour cost

- perfect knowledge of reciprocal productivity

These are some of the more theoretical and technical critics to comparative advantages, but I would suggest two more dialectical critics. The first is the *one-to-one* foundation. One subject specializes its production of a good or a service in which is better than the second subject. Comparing two economic subjects, this theory fits perfectly in understanding how two subjects interact and how, facing reciprocal issues without struggling, they reach a better welfare for both. It is sufficient they analyze reciprocal skills, choose who is better to produce something, make it and then bargain. These steps, necessary to implement the theory, may still be useful for small groups, when every component of the group cooperates. But precisely with the necessity of cooperation emerge a tied problem: nations are selfish. Single persons in a group of people can decide to cooperate for a personal better welfare but also for a common altruistic desire. Thinking about nations, even if they help each other during international emergencies or decide to cooperate in context of international agreement erasing trade barriers, are far away to be altruistic subjects.

2.3.9 Resources endowment and factor prices theorem

We have previously seen what *labour-intensive* and *capital-intensive* mean. Now I provide a better definition: *in a world with two goods (X and Y) and two factors (labour and capital), it is said that good Y is capital-intensive if the ratio K/L used to produce Y is higher than the ratio used to produce good X.* For instance, to produce good Y are necessary 2 units of capital (2K) and 2 units of labour (2L), the ratio *capital/labour* is equal to 1 (2/2). At the same time, to produce good X are necessary 1 unit of capital and 4 unit of labour, the ratio is equal to 1/4. For this reason, it is possible to say that Y is capital-intensive and X is labour-intensive. Suppose now that for another country to produce good Y the ratio K/L (4/1) is equal to 4, while to produce good X the ratio is equal to 1. Even in this second country good Y is capital-intensive and good X is labour-intensive, but which is the reason why ratio is different? It is because capital is less expensive in the second country respect to the first country and the second country uses more capital than the first country to minimize production costs. From this point of view, the H-O model is also described as the *theory of resources endowment*: each country specializes itself in production of the good which uses intensively the productive factor which is relatively abundant and less expensive, and exports this good, while it imports the good whose production uses productive factor scarce and expensive. Directly from the H-O theorem derives another theorem, considered as a corollary, the H-O-S theorem (from the 1970 Economy's prize Nobel *Samuelson (1949)*), so called *factor-price equalization theorem*: *international trade leads to equalization of homogeneous factors relative and absolute remunerations among countries.* It means that international trade should tend to even out wages w of homogeneous work (kind of work requiring same ability, productivity and training) for all countries traders. Similarly for homogeneous (same level of risk and producitvity) capital returns r. Suppose that, without international trade, the relative price of good X (labour-intensive) is lower in country A then in country B, because work relative price w is lower. Than, with trade, country A specializes its production in good X (reducing production of good Y, capital-intensive), relative labour demand raises ensuing a raising in wage w and a decrease in interest rate r. Opposite situation for country B. This theorem proves that international trade tends to reduce differences in w and r respect to absence of international trade. From the national point of view, in most advanced countries (USA, Japan, Germany, etc.) capital is relatively more abundant and international trade tends to reduce real wage of workers and to raise real returns of capital's owners. According to this sentence, why most advanced countries does not limit international trade? According to Salvatore, losses for workers generated by international trade are compensated with profits for capital's owners. Then both categories could benefit from this advantage with a redistributive politics based on an higher taxation for capital's owners and a lower taxation for workers. The effect of international trade on income distribution is based on the strong hypothesis of factor perfect mobility among firms and sectors inside every country. This is supposed to be true in long-term, but analyzing short-term this hypothesis becomes more sustainable. A factor, e.g. capital, in short-term could be fixed or restricted to some specific sector. This is why conclusions of H-O model have to be modified with the *specific factors model.*

Specific factors model Suppose that a country is relatively labour abundant and it produces two goods. Good X is labour-intensive and good Y is capital-intensive. The production of these goods needs both labour and capital, but labour is movable while capital is not, because it is specific to every sector. For instance, capital used to produce good X can not be used to produce good Y and vice versa. If good X is a food product and good Y is a textile product, it is like it there were three productive factors: 1) *labour*, movable between good X and good Y; 2) *natural resources*, land, used just for good X production; 3) *capital*, used just for good Y production.

With the opening to international trade, country specializes its production of the labour-intensive good production, good X, and exports it, importing good Y. This behavior raises relative price of X (so Px/Py), labour demand and nominal wages. A part of labour is reallocated from production of good Y to production of good X. Because of this, sector Y has to pay an higher nominal wage even if Py/Px is slowing down. The effect on real wage is ambiguous: raise of Px/Py and labour derived demand is higher than raise in nominal wage, and so real wage in term of good X falls. On the other side, nominal wage is higher and price of good Y (even because it fights against import) decreases, and so real wage in term of good Y raises. Real wage in term of good X is lower, but real wage in term of good Y is higher. Therefore the effect on real wage is ambiguous: it falls for persons consuming especially good X and it raises for persons consuming especially good Y. The effect on capital is evident: because capital is fixed and specific to each sector, opening to international trade does not take to any transfer of capital from production of Y to production of X. Returns of capital in production of good X raises, while returns of capital in production of Y falls, even because it must compete with import. The conclusion of specific factors model is that international trade has an ambiguous effect on movable factors, it is beneficial for specific factors of goods exported, it is detrimental for specific factors of goods imported.

Empiric relevance Has international trade leveled homogeneous factors returns among different countries in the real world? Clearly not. Wages of engineers, technicians, or manual workers are obviously different among countries. One reason is because H-O-S model has hypothesis not so evident in the real world. There are many differences in level of technology, shipping costs and customs barriers impeding goods relative prices equalization. A second reason is because many sectors does not compete in perfect competition and have not constant return to scale. It is more correct to say that international trade reduced homogeneous factors returns differences. Even if international trade seems to have reduced real wages differences among most industrialized countries, it is important to notice that there are many "forces" which tend to enlarge the process of equalization. An important one is the technological progress. According to Salvatore in 2.1 after the second World War, international trade has reduced differences in homogeneous factor returns among the most industrialized countries which had a similar growing technological progress. On the contrary, differences become bigger among countries with different technological progress, differences which international trade was not able to compensate. Nevertheless factor price equalization theorem tells that international trade leads to reduce differences in homogeneous factors returns, even if it does not tell if trade leads to reduce international differences in term of income per capita.

2.3.10 Rybczynski theorem

Rybczynski (1955) states that:

> the maintenance of the same rate of substitution in production after the quantity of one factor has increased must lead to an absolute expansion in production of the commodity using relatively much that factor, and to an absolute curtailment of production of the commodity using relatively little of the same factor.

Rearranging this statement, we can say that at constant relative goods prices, a rise in the endowment of one factor will lead to a more than proportional expansion of the output in the sector which uses that factor intensively, and an absolute decline of the output of the other good. *Exempli gratia*, if in country A raises endowment of labour L and prices Px and Py are kept constant, then production of good X (labour-intensive) raises more than proportionally while

Table 2.1: Hourly real wage in manufactory sector in main industrialized countries, based on percentage respect to USA hourly real wage

country	1959	1970	1983	1990	2000
Japan	11	24	51	86	111
Italy	23	42	62	79	85
France	27	41	62	102	91
United Kingdom	29	35	53	85	84
Germany	29	56	84	103	121
Canada	42	57	75	84	90
Not weighted average	27	43	65	90	97
United States	100	100	100	100	100

Fonte: Salvatore (2012)

production of good Y (capital-intensive) decreases. It is possible to see this mechanism in fig 2.8. Before the raise of factor L, production in a country open to international trade is represented by point A, where $Px/Py = 1$, tangent the production curve. After the raise of factor L, keeping fixed $Px/Py = 1$, country will produce in the new point B on the new production curve. We have now that production of good X, the labour-intensive good, increases and the production of good Y, the capital-intensive good, decreases, as stated by Rybczynski theory.

2.4 *Flying geese* paradigm

The model of *"Flying geese"* paradigm was elaborated by Akamatsu (1962). This model tells about industrial development and envisages that an underdeveloped country has the possibility to improve and overtake a more developed country. It starts because a more developed country spreads its knowledge to underdeveloped countries to make them export-countries. There are basically two countries categories: leaders and followers. Recalling that geese flocks fly like a V shape formation, the underdeveloped countries are *aligned successively behind the advanced industrial nations in the order of their different stages of growth in a wild-geese-flying pattern.* The leader's need to produce goods in underdeveloped countries derives from internal restructuring due to increasing labor costs. Comparative advantages of the "lead goose" cause its production to move from labour-intensive production to capital-intensive production. Akamatsu identifies the group leaders as the Occidental countries and the group followers as the Asian countries. This theory has four steps:

1. follower countries start to import from more developed countries
2. huge increase of machineries and commodities import, becomes more and more relevant local industry
3. start export of raw material and import of finished product
4. start export of finished product

The peculiarities of follower countries are low wages, raw material low cost and "virgin" local market. Anyway, follower "geese" countries run to catch and overtake the leader "goose" country,

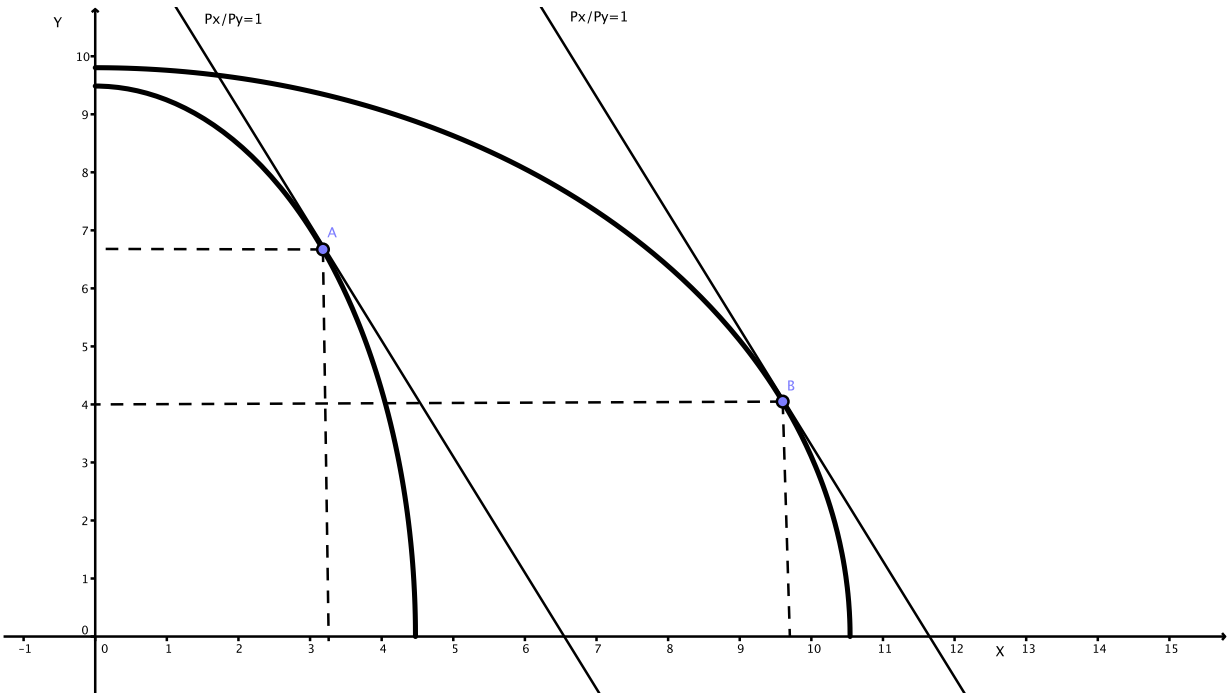


Figure 2.8: Rybczynski model

which to maintain its dominant position must update continuously its products and create new kinds of products in order to satisfy market demand. But follower countries use technology's leader country, so they have always the possibility to overtake the leader.

2.5 International classification of products

In international trade there are two main classification of the products: SITC4 and HS4. These classifications identify sectors of goods exported and imported to enable comparing different countries and years.

SITC4 (Standard International Trade Classification, revision 4) is the classification accepted by the United Nations Statistical Commission at its thirty-seventh session in March 2006.

> The SITC is recommended only for analytical purposes - trade statistics are recommended to be collected and compiled in the Harmonized System instead.

Wikipedia (2013) HS4: Harmonized system is the classification mainly used for tariff nomenclature. It is an internationally standardized system of names and numbers for classifying traded products developed and maintained by the World Customs Organization (WCO). All existing products can be classified into the existing HS utilizing the General Rules of Interpretation.

2.6 Indexes in Economics

Indexes are for economists as number for mathematicians: they play with them building hypotheses and looking for consistent conclusions. But as numbers cannot describe mathematics,

so indexes cannot describe whole economics, they are just part of the story, stressing what customer wants. In the last years institutions, countries and research institutes increased the role and the number of the indexes. They can be considered as a measure and as a guide to action. The main problem about measures is whether they are able to capture what they want to describe. The Programm for International Student Assessment (PISA), by way of example, describes the level in comprehension at a determinate scholar age. It is evident that there could be different age of learning some subjects in different countries. Indexes have the role of guide to action. Often governments carry out their policy driven by indexes, intervening also by changing policy. But if index is not correct, it could guide to an abyss instead of a peak.

According to the "Atlas of Economic Complexity" (Hausmann *et al.*, 2011), all these efforts are important but do not give all answers. The "Atlas of Economic Complexity" starts from one basic idea: knowledge is a mean to improve richness in countries. Economic complexity is related to country prosperity:

> Countries whose economic complexity is greater than what we would expect, given their level of income, tend to grow faster than those that are "too rich" for their current level of economic complexity. In this sense, economic complexity is not just a symptom or an expression of prosperity: it is a driver.

Standard economic theory talks about capital, labour capital, human capital. Many researchers discuss about capital and its differences. While indexes about human capital tend to evaluate how the same level of knowledge is widespread in the country, economic complexity index (from now on ECI) describes the total amount of productive knowledge widespread in the country. This critic has a power and a lack: the power is that in a country with low level of tacit knowledge (we will see later what we mean for "tacit knowledge"), but with a high level of culture, for example one person in two is a philosopher, there would not be so much productive knowledge because knowledge is concentrated in low productive sector and is not distributed. The lack of this critic is that for countries with low general "explicit" culture it is hard to create a huge level of productive knowledge. Economic complexity is a measure which aspires to be a summary of other indexes and a sort of *summa* of many other partial indexes. Many indexes focuses on growth, but Economic complexity index "captures significantly more growth-relevant information than the 6 World Governance Indicators, either individually or combined". Economic Complexity Index (ECI) focuses on complexity of products and the knowledge intrinsic into products, what is usually called "productive knowledge". A country with a high ECI level means that it is exporting products which have a comparative advantage respect to products of other country, a reflection of quality and definitely high productive knowledge. Analyzing past data, it describes the destination where a country is going, its path toward growth. It can sound deterministic, but has a scientific foundation. Between 1970 and 1985, Thailand increased one standard deviation in complexity: this was associated with an acceleration of 1.6 percent per year of country's long-term growth. Many misunderstandings can rise talking about ECI. It uses data about export-oriented growth, openness to trade, export diversification and country size but does not describes them.

Chapter 3

Productivity

Productivity is an economic measure of output per unit of input. Inputs are the classic labour and capital. Output is usually measured with total pieces produced, or revenues and other GDP components. Productivity is calculated by dividing average output per period by the total costs incurred or resources (capital, energy, material, personnel) consumed in that period. Productivity is a critical determinant of cost efficiency. Krugman (1997) affirms that *productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker.* It is a decisive factor to evaluate performances of firms and nations. Which kind of measure are used to calculate productivity? The most known is Gross Domestic Product (GDP), widely used as a measure of the economic growth of nations and industries, because it is a good measure of value-added created in many single processes. Value-added is obtained by subtracting the intermediate inputs from the outputs. Considering another kind of measure, which take into account more productive factors, the most important one is the Total Factor Productivity (TFP) or Multi Factor Productivity (MFP). Total factor productivity is definable as the ratio between a weighted average of capital and labour indexes. There are several ways to calculate TFP. Because it is also known as "Solow residual", we will see this kind of approach.

3.1 The Solow-Swan model and the Solow residual

The "Solow residual" derives from the Solow-Swan model, an exogenous growth model explaining long-run growth through capital accumulation, population growth and increase in productivity. Solow said that the output quantity would be governed by the amount of capital, the amount of labour (the number of people in the workforce), and the productivity of that labour, and economies converge to a steady state situation. The basic equation of the model is:

$$Y(t) = A_t[K_t]^{\alpha}[L_t]^{1-\alpha} \tag{3.1}$$

with $0 < \alpha < 1$, where:

- Y(t) represents the total production in an economy (the GDP) in some year, t
- parameter α is a number ($0 < \alpha < 1$) representing the elasticity of output with respect to capital
- K(t) is capital, measured through the combined value of all companies in a capitalist economy

- L(t) is labour, considered as total population or simply labour force in a nation
- A(t) represents total factor productivity (often generalized as “technology” or “knowledge”)

The implications of this model are very important and it was considered the “neoclassical growth model”. The growth rate of output in steady state is exogenous and is independent of the technical progress and the saving rate. If the saving rate increases, it increases the output per worker by increasing the capital per worker, but the growth rate of output is not affected. Another implication of the model is that growth in per capita income can either be achieved by increased saving or reduced rate of population growth. This will hold if depreciation is allowed in the model. Moreover, with the absence of continuing improvements in technology, growth per worker must ultimately cease. This prediction follows from the assumption of diminishing returns to capital. Finally, this model predicts conditional convergence. All countries having similar characteristics like saving rate, population growth rate and technology that affect growth will converge to the same steady state level. It means that poor countries having the same saving rate and level of technology of the rich countries will reach the same steady state growth rates in the long run. But empirical evidence states that from ’50th the result was, in average, opposite. That is, advanced economies had a growth rate higher than less developed economies, convergence was far away even with a clamorous exception such the Japan’s instance. From empirical point of view, a more specific kind of convergence was relevant: conditional convergence. Convergence happens if countries’ peculiarities are similar, such as:

- institutional rules and structure
- internally free market and presence of commercial policies with other countries
- education and formation policies

Evidence of convergence is stronger inside countries. Income per capita of south USA tended to converge to the income per capita of north USA. Another lack of the Solow-Swan model is that does not consider "entrepreneurial activity" and the importance of institutions, which can ease growth. Moreover, it does not explain how and why technological progress happens.

The residual of the model is a number describing empirical productivity growth in an economy from year to year and decade to decade. Robert Solow defined rising productivity as rising output with constant capital and labor input. It is a “residual” because it is the part of growth that cannot be explained through capital accumulation or increased labor.

Differentiating and rearranging the equation 2.2, we have the “Solow residual” described by the following equation:

$$SR_t = \frac{\frac{\delta Y}{\delta_t}}{Y} - \left(\alpha \frac{\frac{\delta K}{\delta_t}}{K_t} + (1+\alpha)\frac{\frac{\delta L}{\delta_t}}{L_t}\right) \tag{3.2}$$

SR (t) is that part of growth not explicable by measurable changes in the amount of capital K, and the number of workers L.

Even if the Solow-Swan model has been profusely criticized, the Solow residual has still some relevances in the real world. According to Economist (2014), China in 2013 produced goods and services nearly three times more than in 2007 (an amount nearly 9.5 trillion-worth dollars), an astonishing growth. But has that growth come simply from deploying more labour and capital? Or did total factor productivity (TFP), the efficiency with which those two inputs are used, also increase? It is very important to stress that a period of high growth does not necessarily involve a rise in productivity. As long as the amount by which labour and capital grow outpaces any fall in productivity, GDP will still increase. Neither labour nor capital are infinite. In the

long run, improving the productivity with which they are used is the magic ingredient for any economy, the only path to sustainable growth. About China, different studies have suggested that productivity is flagging. The most pessimistic finds that since 2007 TFP has dented growth by about 0.9 percentage points a year. The most optimistic study, by researchers at the World Bank, states that TFP added nearly three percentage points a year to growth from 2000 to 2010, but even they reckon that is 40 per cent lower than in the 1990s. In between these two estimates are three chinese economists, two of whom are with the People's Bank of China. They conclude that productivity increased just 1.5 per cent a year between 1997 and 2012. Divergences are so deep because productivity growth, despite being central to economics, is difficult to pin down. It cannot, after all, be seen. It is easy to determine which one produces more between two workers in the same firm, but for economies is not possible a so close comparison. Instead, economists get at TFP by subtracting the change in capital and labour deployed from the change in overall output, making the "unseen become visible" and calling it "Solow residual". Nevertheless the process needs several accounting somersaults, because of the many assumptions needed (among others: size of capital stock, rate of capital depreciation, level of workers' education) and the wobbly data, especially chinese official data. The most pessimistic vision, made by the economist Harry Wu, who does not trust official GDP measures and so constructs his own, estimates an average annual growth for 2008-12 (6.5 per cent) lower than the official estimate (9.3 per cent). Wu's calculations yield a negative Solow residual. Productivity appears to have gone into reverse. Wu's data maybe are not very trustable, but even estimates from World Bank reveal a worrying trends in terms of TFP. It may be still positive but has quickly slowed, rewarding to the massive accumulation of capital, rather than any improvement in the efficiency with which it is used, the dominant engine driving China's GDP. Is this situation very worrying? According to the author of the article, slowdown in productivity is only natural after three decades of rapid growth like the chinese one. The World Bank estimated that nine-tenth of TFP's contribution to growth in period 2000-2010 derived from a reallocation of labour and capital from farms to factories and from state-owned firms to private sector. Another more worrying factor are bad lending and bad investments decisions. World Bank researches show a strongly negative correlation between growth in lending and in TFP. China's ICOR (Incremental Capital-Output Ratio)[1] rose to 5.4 in 2012 from 3.6 over past two decades. Japan, South Korea and Taiwan were more efficient, with an ICOR level of 2.7 - 3.2 per cent.

3.2 Endogenous theory

Summarizing, according to Solow-Swan model, just technical progress is the growth's driving force and is exogenous. So, in past thirty years, other economists stated about models which could make endogenous missing parts of the Solow-Swan model. They favored a model that replaced the exogenous growth variable (unexplained technical progress) with a model in which the key determinants of growth were explicit in the model. Growth in these models is due to indefinite investment in human capital which had spillover effect on economy and reduces the diminishing return to capital accumulation. According to Romer (1994), he states that *economic growth is an endogenous outcome of an economic system, not the result of forces that impinge from outside*. The basic endogenous model is the so called "AK model". The key property of

[1] is the ratio of investment to growth which is equal to 1, divided by the marginal product of capital. The higher the ICOR, the lower the productivity of capital.

$$ICOR = \frac{\Delta K}{\Delta Y} = \frac{\frac{\Delta K}{Y}}{\frac{\Delta Y}{Y}} = \frac{\frac{I}{Y}}{\frac{\Delta Y}{Y}} \tag{3.3}$$

AK model is the absence of diminishing returns to capital, that is $\alpha = 1$. Recalling the previous Solow-Swan equation, $Y_t = A_t[K_t]^{\alpha}[L_t]^{1-\alpha}$, it becomes

$$Y_t = A_t K_t \tag{3.4}$$

Rearranging this formula by taking log and derivatives, with s the saving rate and δ the depreciation of capital, the growth rate of output is determined by:

$$\frac{\dot{Y}_t}{Y_t} = \frac{\dot{A}_t}{A_t} + sA_t - \delta \tag{3.5}$$

But the growth rate of output depends not only on the growth rate of A, but also on its the level. This means that an increasing A will lead to an explosive path for output, so steady state growth requires $\frac{\dot{A}_t}{A_t} = 0$. The steady state growth rate consistent with the AK model is:

$$\left(\frac{\dot{Y}_t}{Y_t}\right)^{ss} = sA_t - \delta \tag{3.6}$$

The steady state growth rate depends positively on the savings rate and negatively on the depreciation rate, neither of which had any effect on long-run growth in the Solow model. These equations show that to limit the diminishing marginal returns to capital accumulation has a huge effect on the model's predictions of the growth. The fact that the level of technological efficiency has an effect on the growth rate has important implications: it is possible for government policy to affect the level of A, for instance through regulatory policies. But in the real world there is people too. It is necessary human input to create the goods and services that constitute GDP. Extending the AK model with human relevance, it is important to stress a feature: the effect of labour input is determined by the stock of what is called *human capital.* A more skilled individual is assumed to produce more output than an unskilled individual, and the total stock of skills is called *human capital* (H). Human capital can be accumulated through education. Now, output is determined by:

$$Y_t = A_t K_t^{\alpha} H_t^{1-\alpha} \tag{3.7}$$

After a long rearrangement of the previous equation, we have the new growth rate of output given by:

$$\frac{\dot{Y}_t}{Y_t} = As_K^{\alpha} s_H^{1-\alpha} - \delta \tag{3.8}$$

Even with introduction of human capital, we can see that AK model implications are the substantially the same. Anyway, doubts about long-run growth generated by this model are two: non accumulable factors and treatment of human capital. Moreover, Romer (1994) explains well which are the main problems of the theories about endogenous growth. He focuses especially on most criticized fact: the convergence controversy. About the convergence controversy, he states that:

> Differences in output per worker do not necessarily signal large differences in the marginal product of capital. [...] Because the flow of knowledge from the technology leader makes the technology grow faster in the follower country, income per capita will grow faster in the follower as diffusion closes what has been called a technology gap. The speed of convergence will be determined primarily by the rate of diffusion of knowledge, so the convergence dynamics tell us nothing about the exponents on capital and labor. [...] If the same technology were available in all countries, human

> capital would not move from places where it is scarce to places where it is abundant and the same worker would not earn a higher wage after moving from the follower country to the technology leader country. [...] Convergence controversy captures only part of what endogenous growth has been all about.

Romer wrote the following very important words about the neoclassical's view failure in favor of a different perspective:

> If macroeconomists look only at the cross-country regressions deployed in the convergence controversy, it will be easy to be satisfied with neoclassical models in which market incentives and government policies have no effect on discovery, diffusion, and technological advance. But if we make use of all of the available evidence, economists can move beyond these models and begin once again to make progress toward a complete understanding of the determinants of long-run economic success. Ultimately, this will put us in position to offer policy-makers something more insightful than the standard neoclassical prescription - more saving and more schooling.

3.3 Technical progress

Technical progress is an economic measure of innovation. It is possible to categorize it in two different class:

Embodied Technical Progress: improved technology which is exploited by investing in new equipment. New technical changes made are embodied in the equipment

Disembodied Technical Progress: improved technology which allows increase in the output produced from given inputs without investing in new equipment

In the real world, innovations usually does not need to replace an entire part of equipment. It can be improved for better use depending upon the change required. Kaldor (1957) studied a "technical progress function". This function measures technical progress as the rate of growth of labour productivity. It is different respect to the production function because it assumes that, given a preset level of technical progress, output is explained by the level of efficiency by which labor and capital are allocated to production. Differently, technical progress function assumes that, given inputs allocated most efficiently, then the technical progress function assets that output is dependent on the level of technical progress. Thus, the greater the level of investment in technical progress over time, the greater the amount of output in the economy. The technical progress function is described by the following statements:

- the larger the rate of growth of capital/input per worker, the larger the rate of growth of output per worker, of labour productivity. The rate of growth of labor productivity is thus explained by the rate of growth of capital intensity
- in equilibrium capital/input per worker and output per worker grow at the same rate, the equilibrium rate of growth
- at growth rates below the equilibrium rate of growth, the growth rate of output per worker is larger than the growth rate of capital/input per worker
- at growth rates above the equilibrium rate of growth it is the other way round, the rate of growth of output per worker is less than the rate of growth of capital/input per worker

$$\varepsilon_L = \bar{\varepsilon}_K (K/L)^{1-\eta} \tag{3.9}$$

Technology has an important relationship with human capital. Same technology can be applied in two different firms, but output varies with respect to the labour force of that firm. Adaption to new technology is directly proportional to pace of economic growth of the country. Hence labour should be experienced with the technology. Education also plays an important role as it helps in accumulating human capital which in turn helps technology diffusion. Education also helps a person get acquainted with technology efficiently and rapidly. Hence technology is economic specific.

3.4 Human capital

Human capital is the set of competences, skills, ability and emotions acquired by a person during his life, set which is finalized to reach social and economic goals. This set is useful to understand the work capability of a person, even more generally by individuals in a population. Smith's definition of human capital is:

> [...] of the acquired and useful abilities of all the inhabitants or members of the society. The acquisition of such talents, by the maintenance of the acquirer during his education, study, or apprenticeship, always costs a real expense, which is a capital fixed and realized, as it were, in his person. Those talents, as they make a part of his fortune, so do they likewise that of the society to which he belongs. The improved dexterity of a workman may be considered in the same light as a machine or instrument of trade which facilitates and abridges labor, and which, though it costs a certain expense, repays that expense with a profit.

Smith suggests to consider human capital as land capital, building capital, machine capital. The last two can be collected in a bigger family called "material capital". Even if the word "human capital" was named the German (2015) "German Un-Word of the Year" in the 2004 because considered a term inappropriate and inhumane, as individuals would be degraded and their abilities classified according to economically relevant quantities, this definition draw well the sense of a "capital" which people have and, as "capital", can be improved and must be rewarded. Human capital is improvable with education and training. Levin and Raut (1997) made studies about complementarities between export and human capital in economic growth. The question is: to what extent does investment in education affect economic growth? According to G. Psacharopoulos the average earnings of individuals with secondary school education are 2,4 times those of individuals with primary school education. But education investments have clearly high costs. Considering higher education levels, costs increase dramatically, i.e. 4,75 times higher for secondary education relative to primary education (based on Unesco data for eight developing countries), based on earnings differentials and total costs for 30 developing countries. Psacharopoulos calculated that social rates of return to education investment are relatively high, averaging about 25% for primary education and about 15% for secondary education. According to Levin and Raut, they suggest the presence of a high level of sensitivity between average education and export orientation. Their results provide high degree of complementarity between trade policies and education expenditures. Moreover provide new empirical support for the hypothesis that export orientation contributes to economic growth through increasing returns to scale and other sectoral productivity differentials.

But there are some disadvantages with the initial definition. One is we could think of every difference in remuneration that we observe in the labor market as due to human capital. For

example, if I am paid less than a same level coworker must be because I have lower "skills" in some other dimension that is not being measured by my years of schooling. This is the so called "unobserved heterogeneity" issue. But the observed remuneration is a good place to start to understand the conceptual framework, even if it is important to remind some exceptions. Two workers could have different wages because of *compensating differential*, that is a worker is paid less because have some other part of compensation as more pleasant working conditions or better amenities or firm's reputation. Other exceptions are *labor market imperfection* and *taste-based discrimination*. Before analyzing some most used methods to calculate human capital, I want spend some words analyzing the view back human capital, the philosophy, the economic thought. According to Becker, human capital is directly useful in the production process and we can think of it as an unidimensional stock of knowledge or skills directly part of the production function. On the other hand, Gardener sustains that human capital is not unidimensional, since there are many many dimensions or types of skills. He emphasizes the difference between mental and physical skills, making example of how many geniuses and famous personalities were very unskilled in other in some other dimensions. According to Schultz/Nelson-Phelps view, human capital is viewed mostly as the capacity to adapt, while for Bowles-Gintis human capital is the capacity to work in organizations, obey order and adapt to life under a hierarchical society. Spence instead sustains that observable measures of human capital are more a signal of ability than characteristics independently useful in the production process. But which are the sources of human capital differences? These sources are mainly five:

1. innate ability: researches in social biology have documented that there is some component of IQ which is genetic in origin, and there is heterogeneity in human capital even when individuals have access to the same investment opportunities and the same economic constraints

2. schooling: many researches made focus on this argument, since it is the most easily observable component of human capital investment. But it is important to remember that the R^2 of earnings regressions that control for schooling is relatively small, suggesting schooling differences account for a relatively small fraction of the differences in earnings. Therefore, there is much more to human capital than schooling

3. school quality and non-schooling investment

4. training: this is the component of human capital that workers acquire after schooling, often associated with some set of skills useful for a particular industry, or useful with a particular set of technologies

5. pre-labor market influences: peer group effects to which individuals are exposed before they join the labor market may also affect their human capital significantly

Even if human capital is a set difficult to calculate, it is possible to make an effort and try to analyze it better, through the so called "human capital accounting". The objectives of "human capital accounting" are basically four:

- provide cost-value data for managerial decision regarding acquiring, developing, allocating, and maintaining human resources so as to attain cost-effective organizational objectives

- provide information to monitor the effectiveness of human resource utilization

- provide information for determining the status of human asset whether it is conserved properly; it is appreciating or depleting

- assist in the development of effective human resource management practices by classifying the financial sequences of these practices

We discuss now about some most famous "human capital accounting method".

Lev-Schwartz model This is a process useful to identify and report investments made in the human resources of an organization that are presently unaccounted for in the conventional accounting practices. According to the Lev and Schwartz (1971) model, the value of human capital represented by a person of age is the present value of his remaining future earnings from his employment.

For this they propose that the value of human capital is determined as follows:

- all employees are classified into specific groups according to their age and skills
- the average annual compensation is determined for different age groups
- the calculation of total compensation that each group mentioned in the previous point will be up to retirement age
- the total remuneration will be calculated at a rate discounted cost of capital. The value arrived at will be the value of the asset / human capital

The value of human capital embodied in a person who is τ years old, is the present value of his/her future earnings from employment and can be calculated by using the following formula:

$$E(V_\tau) = \sum_{t=\tau}^{T} P_\tau(t+1) \sum_{i=\tau}^{t} \frac{I_i}{(1+r)^{t-\tau}} \tag{3.10}$$

where:

- $E(V_\tau)$ = human capital value of a person with τ years old
- I_i = The person's annual earnings up to retirement. These values are plotted through the profiles of income
- r = Discount rate specific to the person
- t = Retirement age
- $P_\tau(t)$= Conditional probability of an elderly person τ to die in year t

Looking better, the Lev and Schwartz's idea is that the value of the organization's human capital is no more than the sum of the values of human capital of individuals working in the organization. But using this view, there are some disadvantages:

- this model implies that the condition for future work the employee does not change with the time of his professional life, but will remain the same in this
- the approach does not take into account the possibility of a worker to withdraw from the organization before his death or retirement. As such, it is unrealistic
- ignores the variable of career movement of workers within the organization
- it does not take into account the changes in the functions of workers

Morse model Another economist who tried to calculate human capital was Morse (1973). He sustained that the value of human resources is equivalent to the present value of net benefits obtained by the service organization of its employees. The method involves the following steps:

1. Determine the gross value of services to be provided by employees in the future, based on their individual and collective capabilities

2. Determine the value of future payments (direct and indirect) for employees

3. Determine the excess of the future value of human resources (as in 1.) on the value of future payments (as in 2.). This represents the net benefit to the organization's account of human resources

4. The present value of net benefit is determined by applying a discount rate predetermined (usually the cost of capital). This amount represents the value of human resources for the organization

For Morse the concept of human asset and human capital presented by Lev and Schwartz equations are not alternative ways of seeing the human resources are complementary. Each one represents the present value of a share of gross value, given by employees to an organization. Indeed, the following equation is an integration of basic Morse equation and Lev and Schwartz equation:

$$A = \sum_{i=1}^{N} \int_{\tau}^{T} \frac{G_i(t)}{(1+r)^{t-r}} dt + \int_{\tau}^{T} \frac{X(t)}{(1+r)^{t-r}} dt - \sum_{i=1}^{N} \int_{\tau}^{T} \frac{E_i(t)}{(1+r)^{t-r}} dt \tag{3.11}$$

where:

- A = value of human assets to a formal organization

- N = number of individuals currently employed by the organization

- τ = current time

- T = highest time at which an individual currently employed leaves the organization

- $G_i(t)$ = gross value of services rendered by individual i at time t to the organization

- $E_i(t)$ = direct and indirect compensation given individual i at time t by the organization

- X_t = value of the services of all individuals currently employed working together in excess of the value of their individual services at time t

- r = real value of money

The first two plots represent the present value of gross services assigned to the organization, for all existing employees, the third represents the value of human capital currently employed in the organization.

Flamholtz model In the model suggested by Flamholtz (1999) the historical cost method, or contract, is to capitalize all costs associated with recruiting, selection, hiring and training and amortize these costs within the projected life of the asset. There are several limitations of such measures. Thus, the economic value of an active human does not necessarily correspond to its historical cost. On the other hand, any appreciation or depreciation may be subjective, with no relationship to any increase or decrease in the productivity of human assets. Finally, the costs associated with recruitment, selection, hiring, training, placement and development of employees might differ from one individual to another within a company. Soon, the historical cost does not result in comparable values of human resources.

According to Andrade and Sotomayor (2013), many economists proposed other models, but there is evidence of use only of Lev and Schwartz model and Flamholtz model to several companies, with the Flamholtz model used in experimental study by industrial and services companies.

Chapter 4

Knowledge

"Educated workers may be able to adapt more quickly to the sophisticated technology and rapid production changes required for competitiveness in world markets." Levin and Raut (1997)

4.1 Knowledge and information

Before analyzing the difference between information and knowledge, we must do a step earlier, analyzing the difference between information and "big data". Big data is an all-encompassing term for any collection of data sets so large and complex that it becomes difficult to process using on-hand data management tools or traditional data processing applications. In some way, big data and information are the same, with a difference. The ideal way to split up data and information is to look at them as a checkpoint and an endpoint. In this view, data refers to the figures, statistics and other hard facts that can be analyzed for further insight. The insights that come from processing and analyzing data are then considered information. In other words, without those insights, data is meaningless and no information can be taken from it. In short, processing data yields information. This separation works in practice, but it does have some snags. Sometimes the information resulting from processing data can be "demoted" to the level of data and be processed again to yield more insights (more information). To make this work logically, we need to broaden the definition of data to anything that is processed or analyzed and tighten the definition of information to mean insights on the subject or problem being considered. In this sense, information is anything that provides meaningful insights to the observer at first glance, while data is anything that requires more processing or analyzing before it yields those insights. So the difference between data and information depends on the purpose of the individual looking at it. What is merely a piece of data to one person may be a vital piece of information to another person. For example, the market value of a particular house is very likely important information for the homeowner, but it is merely another piece of data to an economist tracking housing prices in the city over time. Information is a collection of facts from which conclusions may be drawn. "Statistical data", or data, is processed, stored, or transmitted. Information is data extracted or transformed and presented to draw insights. Data is the lowest level of abstraction from which information and then knowledge are derived. But I think that, even if data are a common denominator for both information and knowledge, the way data (and big data too) are extracted and transformed matters.

Crossing from the old to the new century, economy has lived a general blunder. Economy shifted from *industrial* to *informational*. Informational economy is a term born after economists understood that economy was no more industrial and strictly productive, but richness generated

by services was growing more than gross domestic product (GDP). This kind of economy was based on the idea that information was a strategic resource. A statement by Daniel Bell helps to clarify: "A post-industrial society is based on services. What counts is not raw muscle power, or energy, but information. A post industrial society is one in which the majority of those employed are not involved in the production of tangible goods." Bell (1976) Every day we are "bombarded" with tons of information. Stonier (1990) states:

> Information exists. It does not need to be perceived to exist. It does not need to be understood to exist. It requires no intelligence to interpret it. It does not have to have meaning to exist. It exists.

In my opinion, the so called "New Economy" was based on a bad interpretation and on a misleading conviction: information was perceived as knowledge, and its diffusion could be so sharp and pervasive as it was almost costly insignificant, because so easy to replicate. The cost of producing the first copy of an information good is normally quite costly, but reproducing those goods is often negligible. An example is writing a book. I agree with Stonier and Bell about the importance of information. But are we sure that information and knowledge are so similar? Stonier wrote: "information requires no intelligence to interpret it." This small sentence marks the difference between information and knowledge. Knowledge requires a great intelligence to interpret it. As information, knowledge is easy to reproduce. But knowledge is much more difficult to be understood. Information requires a person who is able to read. Knowledge requires a person who is able to think how interpret it, with a background of skills useful to take knowledge and make something with it. Even if somebody would still consider similar knowledge and information, another difference comes. Information is separated from learning processes which have generated it. A circumstance happens and generates information. The circumstance and the information are not connected. Knowledge is hardly connected with learning processes which have produced it. More, it is part of learning processes of knowledge, it can be created just using knowledge itself. According to Tzu, maybe one of the most sentence is "If you know the enemy and know yourself, you need not fear the result of a hundred battles." But Sun Tzu was talking about information, that is to know as much as possible about circumstances and peculiarities of the enemy. In this way, information is useful to win battles, not to create richness.

4.1.1 Knowledge as commodity?

According to Rifkin (2001), he sustains that we are shifting from *physical capitalism* into a new era, so called *cultural capitalism*.

> An Ownership of physical capital, once the heart of the industrial way of life, becomes increasingly marginal to the economic process. Intellectual capital, on the other hand, is the driving force of the new era and much coveted. The changes taking place in the structuring of economic relationships are part of an even larger transformation occurring in the nature of the capitalist system. We are making a long-term shift from industrial to cultural production. We are making the transition into what economists call an 'experience economy' - a world in which each person's own life becomes, in effect, a commercial market. Selling access to cultural experiences is testimony to the single-minded determination of the commercial sphere to make all relations commercial ones.

Knowledge has always been an important resource to production. Even in the very remote past, production of "homo sapiens" has been an activity different from animal or natural activity, because made a great use of human cerebral and intellectual skills, becoming productive force

during Modern Age. This was possible applying the basis of modern science, the galilean method of reproducible cause and effect. Thanks to reproducible cause and effect method, humans became able to invent and building machines that reproduce hundreds and thousands times the same process, generating hugh economy of scale. So investing in knowledge and education became much more profitable respect to the method of "learning by doing", method used for example by farmers during Middle Age, that ignored economy of scale. What I mean is the so called "economy of knowledge". Classical economists may have turned up their's nose, because classical economy affirms that growth is given by accumulation of capital and earning from a different allocation of resources caused by markets and entrepreneurial ability. But we can talk of "economy of knowledge" every time knowledge produces economic value, that is knowledge does not change raw material, but it creates new knowledge which will be used to change raw material with the help of machines and create a benefit, or reduces costs with the introduction of a new productive process, or also creates a new product or class of products. What matters is that knowledge creates value. For example, a dress is usually paid much more than its real value of production. Because that dress has intrinsic qualities which are not just the value of cloth or the time a seamstress needs to produce the dress. We are living in a period where labour force is changing its way to behave and to be used. Labour is not just material or manual work, but it is almost just a *cognitive* work. Not only professors or scientists or doctors, but also workmen need to *know* how machines operate, using brain instead of muscles. In classical economy, economic value was created using fixed level of productive factors (land, labor and capital). Knowledge was used just to study different allocations of resources, and what could give a progress was just new technologies, intended as new technique of production. This vision of the economy was good for a subsistence economy. In rich countries subsistence is not more a necessity. What gives new value is imagination, creativity, communication. All under categories of knowledge. So far it is clear that knowledge has a very important role in economy. What has made knowledge crucial is diffusion. Diffusion makes knowledge affordable and available to many people. Uses of knowledge are not exclusive, they add new value to knowledge every time knowledge is used and shared, with no additional costs (or negligible). In this view, knowledge feeds knowledge. "Economy of knowledge" shifts vision of the economy from the rational consumption of scarce resources to a net where knowledge can be shared and re-used, without limits, of what society knows and knows make. Classical economic resources are considered scarce, divisible and instrumental. Knowledge instead is:

- not scarce because is usually easy to reproduce
- not divisible because costs and profits are tied to social processes
- not instrumental because it does not change just machines, but relations and preferences

In other words, knowledge is multipliable, sharable and reflexive. Even using the classical economy point of view, it is important not consider knowledge as a normal economic resource, because the risk is to reduce it as other replaceable resources and not as a fundamental resource. It is important to take advantage of knowledge's anomalies because are what give a hugh economic value (even not easily monetizing or calculable). What shall we do? It could be a good way to let knowledge free and to invest in production of new knowledge. Somebody could object that patents are a sort of limit to diffusion of knowledge, while some others could affirm that patents and defense of intellectual property are a great push to new inventions and so to possibilities for new processes and new technologies. It is a debatable argument, but I think that *in medio stat virtus*. Even if on one side the Mumford and Winner's sentence: "patent monopoly is a device that enables one man to claim special financial rewards for being the last link in the complicated

social process that produced the invention" is sharable, on the other side patents are the results of high knowledge sustaining inventions, not just its limit.

This new era could lead to much more social differences. *Digital divide* is becoming much more huge respect to property divide. A big part of world's population still fight for survival, when the richest fifth of the world's population "spends almost as much of its income accessing cultural experiences as on buying manufactured goods and basic services." Cultural capitalism has a different competitive advantage, because it is given by "intellectual capital". If we would be able to maintain cultural spaces not commercialized, this age could be a economic renaissance. The contrary may happen if we would reduce knowledge as a commodity, thinking it as classic economic resource, scarce, divisible and instrumental.

4.2 What kind of knowledge?

"Markets and organizations allow the knowledge that is held by few to reach *many*." [1] As already said, human capital research focuses on evaluate the same level of knowledge in a country, but what does not tell is the productiveness of this knowledge. Classical economic resources are scarce, divisible and instrumental. Knowledge is not scarce because in its nature is reproducible. It is divisible, because everybody can use knowledge. It is not instrumental because it changes preferences and relations. Knowledge produces value if it free to go around, if it is not tied up to costs and revenues, if everybody can choose and use it.

Hausmann *et al.* sustain that relation between countries and comparative advantage is important to distinguish knowledge in two kind: explicit and tacit. Explicit knowledge is a kind of knowledge easy to acquire. It is easy to have, like reading a newspaper or a book, listening to radio or TV. It is definitively not knowledge but information. Tacit knowledge is much more difficult to be acquired. It consists, by way of example, in expert profession, engineering and chemistry. It is difficult and costly to transfer. It is definitely the constraint for growth and development in countries. Because of this, workers tend to specialize. Some workers will learn how to build engines, other how to write contracts, other how to operate on patients. According to ECI, there is just a kind of knowledge important for countries to grow, and it is the last one: tacit knowledge. In my opinion, this point is only partially correct. I agree that tacit knowledge is deeply related to build innovative and high probability exported products. I don't agree when the attention is focused only on tacit knowledge, considering less important explicit knowledge and especially another kind. ECI misses one kind of knowledge: I define it "human capital knowledge." Let me consider basic knowledge, what we learn when we are children, as speaking, reading, counting. Children learn fables and how to solve trivial problems. Is this knowledge tacit or explicit? It is related to production or information? This is a question that ECI does not face. In my opinion, these are important tools, not clearly definable with the classification used by ECI. It is not everything productive knowledge. It is scientific evident that in a country with low economic complexity the level of growth is lower. But how much is because of low productive knowledge? Could be caused by low "human capital knowledge"? African countries have low ECI not only because they export goods with low tacit knowledge, one reason can be because they have also a low "human capital knowledge". I think "human capital knowledge" is more important respect to how few it is considered by ECI. Let imagine a wonderful tree, big, leafy and rich of fruits. This tree produces every year many fruits. Many people eat these fruits. There was a time when this tree was very small. It needed water and soil to grow. It had good nutriment, it is evident looking at how big and leafy and rich of fruits is now. What if water were not enough? It would have not grown so well, and its fruits were not so good. So is for

[1] Atlas of Economic Complexity

people and knowledge: without a good level of "human capital knowledge", the productive one may be less useful.

4.2.1 Diversity and ubiquity of (tacit) knowledge

According to ECI, things are easy so far. A country invests in knowledge, more exactly tacit knowledge, and makes products with high knowledge. These products become more desirable by other countries, which buy willingly products with high intrinsic tacit knowledge. Products are made by many and many factors. Everything starts with ideas, but ideas alone are not sufficient. I started my thesis with an idea, then I looked up for an available Professor, explained my idea, informed myself about the argument, looked for other researches, planned how to explain my idea and verifying it with ABM. A thesis must be written by only a person who makes all the chain. This is of course a trivial example. A better example can be build an airplane, not a Boing 747 or a military plane, but a seaplane. In the world there could be maybe someone able to build it alone but he would be just an exception and surely he will needs many and many hours. If we have the dream to build a seaplane, it would be better for us to find engineers, unskilled workers and specialized workers. Everyone of them holds capacity of knowledge equal to one *personbyte*. A product needs very diversified approach before enter in the market. Having willingness to make a product that needs 10 different personbyte, it can be made only if we have 10 different personbyte of knowledge. So is for a country: a country can make a product that needs 100 different personbyte only if it has 100 different personbyte of knowledge. Diversity is clearly important. The other important factor is ubiquity. It is definable as the number of countries that make a specific product. Using this terminology it is possible to tell that complex products, those that contain many personbytes of knowledge, are less ubiquitous. But there are some products that are very low in ubiquity. Raw diamonds are quite rare in the world, having a very low ubiquity, even if it does not mean they need many personbyte to be produced. It it possible to say that distribution of knowledge corrects ubiquity informations and vice versa. A country becomes more rich not only with high tacit knowledge, but also if it distributed among workers-citizens. This is an important result that makes follow an another important one: countries do not produce what they want, but what they can.

4.3 ECI and its evolution: PCI

So economic complexity is important: it's a measure of country income level per capita and describes future growth. We have seen how knowledge and its distribution are very relevant. So far starts one of the most famous problem: the "chicken and egg problem". In the one hand, countries cannot create products that require capabilities they do not have. On the other hand, there are scant incentives to accumulate capabilities in places where the industries that demand them do not exist.

"New capabilities are more easily accumulated if can be combined with ones that already exist". I want to focus my efforts analyzing the Product Complexity index (from now on PCI). A producer of cars internal components tends more easily to produce components for trucks respect to a textiles industry, as a producer of shirts to produce pants. This is what Product Complexity Index try to show: "communities tend to have similar levels of complexity positive relationship between how centrally located the communities are in the product space and how complex their products are." A figure 4.1 may help to understand how it works. Nodes are products, nodes with the same color are sectors (as Electronics, Machinery, Food etcetera). High density of nodes means that is relatively easy to produce goods because only few new knowledge are needed to

make new products. If density is low, it is more difficult to make new products because knowledge in that sector is low. Links connect nodes with high probability to be co-exported.

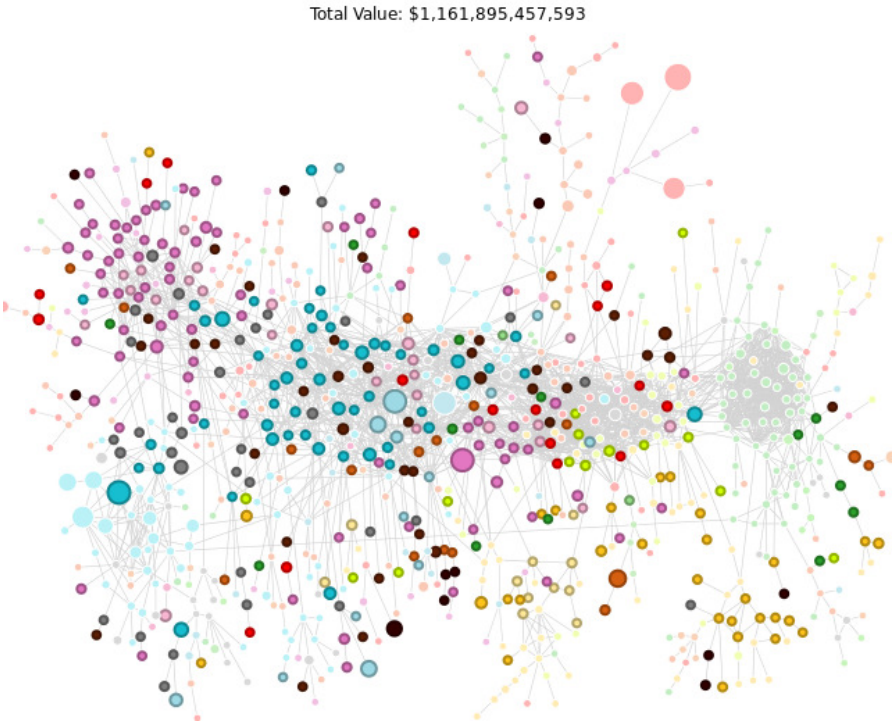


Figure 4.1: Product space for USA's export in 2010

Every sector has a different level on complexity and different location. These different levels describe different levels of difficulty in making products. Machinery and electronics are very complex and centrally located with many connections. Petroleum and cotton are low complex and have few connections. Food or textiles are half-way complex and have an average number of connections.

4.4 Technical background to ECI

HH defined a matrix M_{cp} as a matrix that has valus 1 if country c produces product p and 0 otherwise. It is possible then measure diversity and ubiquity simply by summing over the rows or columns of that matrix. Formalizing, we have two equations:

$$Diversity : k_{c,0} = \sum_{p} M_{cp} \tag{4.1}$$

$$Ubiquity : k_{p,0} = \sum_{c} M_{cp} \tag{4.2}$$

Now we need to correct the information that diversity and ubiquity carry by using each one to correct the other, with the aim to generate a more accurate measure of the number of capabilities available in a country, or required by a product. For countries, it needs to calculate the average

ubiquity of the products that country exports, the average diversity of the countries that make those products and so forth. For products, it needs to calculate the average diversity of the countries that make them and the average ubiquity of the other products that these countries make. It possible to calculate now:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} \cdot k_{p,N-1} \tag{4.3}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_c M_{cp} \cdot k_{c,N-1} \tag{4.4}$$

and then insert the first into the second one:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} \frac{1}{k_{p,0}} \sum_{c'} M_{c'p} \cdot k_{c',N-2} \tag{4.5}$$

and then

$$k_{c,N} = \sum_{c'} k_{c',N-2} \sum \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}} \tag{4.6}$$

Rearranging we have:

$$k_{c,N} = \sum_{c'} \widetilde{M_{cc'}} k_{c',N-2} \tag{4.7}$$

where

$$\widetilde{M_{cc'}} = \sum_p \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}} \tag{4.8}$$

It is important to notice that 4.7 is satisfied when $k_{c,N} = k_{c,N-2} = 1$. This is the eigenvector of $\widetilde{M_{cc'}}$ which is associated with the largest eigenvalue. Since this eigenvector is a vector of ones, it is not informative. We look, instead, for the eigenvector associated with the second largest eigenvalue. This is the eigenvector that captures the largest amount of variance in the system and is our measure of economic complexity. Hence, is possible to define the Economic Complexity Index (ECI) as:

$$ECI = \frac{\vec{K} - < \vec{K} >}{stdev(\vec{K})} \tag{4.9}$$

where $<$ and $>$ represent an average, stdev stands for the standard deviation and $\vec{K}$ the eigenvector of $\widetilde{M_{cc'}}$ associated with second largest eigenvalue.

4.5 Critics to Atlas of economic complexity

The main criticism against Atlas of Economic Complexity has moved by physicists specialized in complex systems. According to Cristelli *et al.* (2013), they agree with the importance of economic complexity, especially because their researches tell that actually countries produce all possible products they can, given the level of technology and development in each country. This contrasts with ricardian view of countries' specialization, that is to create niches with high degree of specialization. Except this, Cristelli *et al.* criticize HH's Atlas because it suffers of

conceptual and practical problems, but the main critique is about mathematical aspect. In particular, HH method is based on linear relation (arithmetic average) between ubiquity of a product and competitiveness of exporters. According to critics, this relation is instead highly non linear, especially talking about complexity of products and fitness of countries producing them. Cristelli *et al.* based a method *with the introduction of coupled non-linear maps between the fitness of countries and the complexity of products characterized by a fixed point which defines a new metrics for determining the relative strength of countries and products in the context of the international exports. Each iteration of the algorithm adds higher order information on these quantities up to reach broad Pareto-like distributions for the two metrics at the fixed point.* After many calculations, at first they find out that some countries export a large fraction of all products (highly diversified countries), and some others export a very small fraction of products (poorly diversified countries). At the same time, the products exported by a small number of countries (less ubiquitous products) are exported practically only by highly diversified countries. Moreover, countries evolve becoming more and more complex and acquire a higher degree of diversification rather than specialization: this contrasts with economic standard view. These authors talk also about hidden capabilities. Every country has inside a certain level of endowment, called capabilities, which represent all the resources of the economy of a given country and the features of the national social organization making possible the production and the export of the basket of tradable goods by the same country. According to HH, these capabilities are the fundamental bricks behind an economy. Capabilities are usually non-tradable and are very difficult to measure and compare from country to country. In other words, capabilities are all the intangibles assets which drive the development, the wealth and the competitiveness of a country. However, listing all the capabilities is impossible. Furthermore they vary enormously from country to country depending on political organization, history, geography etc. and we cannot define a universal standard measure for them. The problem is that is very difficult to categorize, quantitatively analyze and compare capabilities. It is possible only to represent a framework, where countries and products are the visible element while capabilities are in the middle even not visible. But, because products are visible and we know which capabilities are needed to produce a certain product, we can suppose which capabilities has a country producing a certain good. Actually, critics affirms that the mathematical approach of HH is wrong. Ubiquitous products, in the "capabilities" picture, should have a low degree of complexity requiring only a small amount of capabilities to be produced so that even countries with few simple capabilities can produce them. On the other side, most exclusive products are exported only by the most diversified countries. The most diversified countries show in this way to own so many capabilities to be able to produce a large variety of goods from very simple to very complex. This calls a strongly non-linear relation between the competitiveness and wealth of countries and the complexity of the products that they export. Introducing a non-linear relation, based on the matrix M_{cp}, relating the quality and complexity of products Q_p^* to the fitness of countries F_c^*, it is possible to see the triangular structure(4.2). This kind of structure stresses the idea that, while the fitness of a country is defined by the sum of complexities of its products, indeed the complexity of a product is bounded by the development of the poorly diversified producers. Critics of HH method take into account a specific aspect, the Method of reflections, an original approach to the measure of product sophistication and economic complexity, based only on product's international trade data. The main argument of this method is that the required capabilities for the production of one good can only be partially substituted by some others and so the set of capabilities in the economy determines what can be potentially produced in it. After Cristelli *et al.* even Kemp-Benedict (2014) criticizes the way this method is used, mainly from the mathematical point of view. According to the first critics, with their calculation they affirms that the MR ranking not correctly some countries with particular characteristics. Countries with very large diversification

are systematically penalized and medium size countries tend to be favored by MR algorithm. The reason is because the variables representing competitiveness are linear averages, and there is an unclear dependence on the level of diversification. So it is possible to understand why China and India are poorly ranked while poorly diversified countries are over-ranked. Average complexity of China and India, which have a very diversified product space and export, are very close to countries less diversified such as Romania, Cyprus and oil exporters.

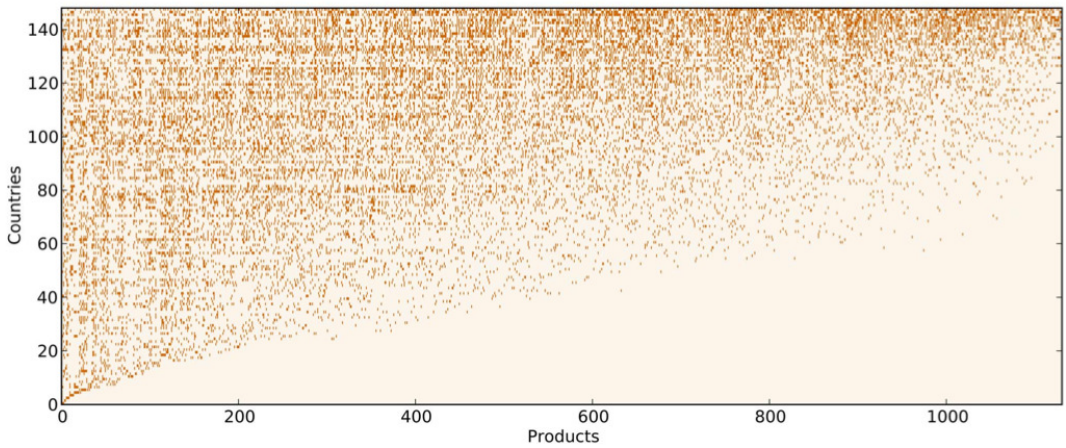


Figure 4.2: Graphical representation of the experimental M_{cp} matrix for the year 2010 after reordering of rows and columns by respectively decreasing F_c^* and increasing Q_p^*

Chapter 5

Policy analysis and Agent-based Simulation

Policy, intended as a set of actions adopted or proposed by a government with the aim to make people achieving desired outcomes in social systems, is basically grounded on trade-offs. This is why analysis of the policy is really important to help government in understanding which are people's preferences and choosing policies with best outcomes. This is possible with modern tools able to predict actions and outcomes. Among policy alternatives, it is important to clarify the best procedure in order to get a decision. This procedure is well described in 5.1 , the policy analysis cycle by Patton and Sawicki (1993). In the first step, the policy analyst verify, define

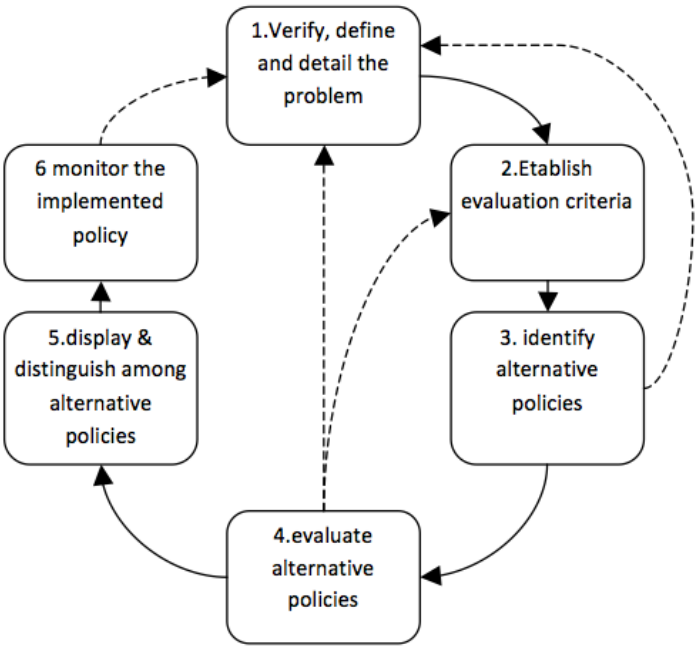


Figure 5.1: Policy analysis cycle

and detail the problem. It is sometimes the most important part, because often different actors see the problem in different way, looking only from their own perspective. Analyst's role is to understand these differences and find a solution good for all interested parties. During the second phase analyst establish evaluation criteria, trying to chose those criteria that are central to the problem and most relevant to the decision makers in the implementation process. Analyst goes then to identify alternative policies. Benchmarking and past experience are in general useful to identify policy alternatives, but the list of possible alternatives is long since there are many combinations for the policies. It is then the turn of evaluate different policies. These different policies can be tested with many different methods, such as costÐbenefit analysis, programming, institutional analysis, and quantitative analysis. The final phase is the monitoring, maintenance and evaluation of the implemented policy. Policy analysts are highly involved in analysis ex-post, to understand if a failed policy did not produce the desired results because of an incorrect underlying theory or because a mismatch between policy tested and policy implemented.

Policy implementation is a top-down procedure, but we must take into account that policies affects individuals. For this reason is important that tools used to predict human reactions outfit a good inspection of links between individual behavior and global outcomes. The second feature necessary for policy tools is a good reflection of reality, because assumptions must match as much as possible characteristics of a specific policy problem. Each step of the policy analysis cycle has specific property, and requirements for policy analysis tools can be classified in five areas:

- Problem definition
- Evaluation criteria
- Identification of Policy alternatives
- Decision support for selecting policy alternatives
- Monitoring implemented scenarios

Policy analysts use various tools in different phases of the policy analysis cycle (e.g. surveys, brainstorming, sensitivity analysis, institutional analysis etc.) (Patton and Sawicki (1993)), and it is a common practice to select a combination of tools. Computational tools are more often applied to cover more scenarios and possibilities that non-computational tools cannot explain. I am going to illustrate why I have chosen a computational tool, and explain the core of my thesis, that is modeling, simulating and proving ideas written upon. Agent Based Simulation (from now ABS) is a way to compute actions and interactions of agents which behave following inputs given them. Why ABS is the best to way to simulate evaluate policies' effects? The article written by Ghorbani *et al.* describes reasons why ABS should be an "inevitable tool for policy analysis". From computational point of view, major approaches currently used are:

- Neo-classical Modeling (NEM)
- Traditional game theory (TGT)
- System dynamics (SD)
- Serious gaming (SD)
- Agent-based Modeling (ABM)

Neo-classical models is used mainly for market-related policy problem, because its focus on maximizing profit, competition and income distribution. This model has good mathematical

grounds, but assumptions provided are too strict: full rationality of individuals and complete information.
Traditional game theory is basically used to understand actor behavior and decision making in policy problems. It is useful if the number of players is low because it is possible to analyze joint product of separate choices and actors are aware of their interdependence. But this kind of theory is not very suitable because does not provide a macro perspective, interactions between actors are limited and assumptions - such as perfectly rational actors, complete information, self interest - are strong.
System dynamics is a computational approach which has its roots in differential equations. Real problems are represented in term of stocks, flows and information. It is a popular method because of its ease and availability, but it needs as much assumptions as simulation grow bigger. More assumptions makes the model less flexible. Essentially, SD has power if simulation runs as an indivisible whole.
Serious games are a kind of simulation where players are real people and they get the chance to make decisions about virtual events. The purpose of SG is to understand how people act and react when different (real or virtual) choices come, to study the decision process and possible outcomes. SG can be computer-based but also role-play among human players. The limit is that human sample considered for the game is necessarily much smaller than real population, and therefore unreliable to extrapolate to real world scenarios.
Agent-based Modeling is a computer-based modeling approach that enables the exploration of the consequences of complex assumptions, describing those situations where standard methods of predictive policy analysis are least effective. It is possible to design irrational agents with incomplete information in uncertain and different situations. The main advantage of ABM over other modeling approaches is "that it captures emergence, linking individual behavior to system level behaviors. This results in a natural representation of a system's global behavior as well as adding more flexibility to possible outcomes." Agent-based modeling is similar to SG, with the difference that the real people in serious games are represented as artificial agents in ABM. A "strengths and weaknesses" chart of all methods described above is visible in figure 5.2. ABM covers many of the benefits of SG because both tools deal with populations of individuals. Even if ABM looks to fit better than previous methods, there are still areas for improvements. It is a descriptive method rather than predictive. Simulations are extensively addressed when using visual tools such as NetLogo, but it is difficult to address researches like social emergencies because are not always visually recognizable in a simulation. Another drawback of ABM is that is difficult modeling social structures within agents because it misses lifelikeness, considering that agents and structures are interrelated but separate concepts.

5.1 Why NetLogo?

To reach a good ABM result it is necessary a program used by many researchers, professors and students. The most known program is NetLogo. NetLogo basically is a multi agent-based programming language, integrated and programmable modeling environment. It has its basis in Logo programming language, and was designed to be "low threshold and no ceiling".

5.1.1 Programming language

My project needs a good knowledge of the program to be built. NetLogo offers good flexibility in giving agents the behavior which 'creator' want to give to agents. NetLogo has eight kind of extensions:

		NEM	TGT	SD	SG	ABM
Problem definition	communicate with experts	✗	✗	✔	✔	✗
	parametrize problem	✔	✔	✔	✔	✔
	identify and define population	✗	✔	✗	✔	✔
	identify resources, system characteristics & boundaries	✗	✗	✗	✔	✗
Evaluation Criteria	specify measures	✗	✗	✗	✔	✗
	measure clarification & link with problem definition	✔	✔	✔	✔	✔
	identify & consider extreme values	✔	✔	✔	✗	✔
Identification of Policy Alternatives	identify policy attributes	✗	✗	✔	✔	✔
	link policies to evaluation measures	✔	✗	✔	✔	✔
	include technical, political & economical aspects	✔	✗	✔	✔	✗
	present policy alternatives	✗	✗	✔	✔	✗
Decision Support for Selecting Policy Alternatives	compare alternatives	✔	✗	✔	✗	✔
	participatory decision making	✗	✗	✗	✔	✔
	answer what-if scenarios	✔	✗	✔	✔	✔
	explore possible reactions towards policies	✗	✗	✗	✗	✔
	test extreme values	✔	✔	✔	✗	✔
Monitoring	compare before & after situations	✔	✔	✔	✔	✔
	track reactions	✗	✗	✗	✗	✔

Figure 5.2: Policy analysis approaches and type of problems they can be used for.
Note: NEM: Neo-classical equilibrium modeling. TGT: Traditional game theory. SD: System dynamics. SG: Serious gaming. ABM: Agent-based modeling.

- Arrays and Tables
- Matrices
- Sound
- Robotics
- Profiler
- GIS
- Bitmap
- Quicktime

I used one specific: matrices. Every agent has a MxN matrix, initially a 4x1 matrix (remember: M are rows, N are columns). Every row of the matrix represent a sector, and the value is the probability of the agent to have that level of technology. The more first rows have high numbers, the higher is the probability for a nation to have sectors with low level of technology. The more last rows have high numbers, the higher is the probability for a nation to have sectors with high level of technology. Maybe I have done an approximation, but quite good: high level of technology means high level of knowledge. High level of technology means, according to Hausmann *et al.*, high level of exportation. Imagine a Cartesian coordinate system, first quadrant, the one with x and y axes positive. On the bottom left of the quadrant we will find nations with low productivity (y-axis) and with low technology (x-axis). On the top right, nations with high productivity and high level of technology.

5.1.2 Example of NetLogo

The following example is one of the basic sample model in NetLogo. Have you ever been at a party and noticed how people cluster in groups? You may have also noticed that people don't just stay in a group. As they circulate, the groups change. If you watched these changes over time, you might notice patterns. For example, in social settings, people may exhibit different behavior than at work or home. Individuals who are confident within their work environment may become shy and timid at a social gathering. And others who are reserved at work may be the "party starter" with friends. These patterns can depend on the type of gathering. In some settings, people are trained to organize themselves into mixed groups; for example, party games or school-like activities. But in a non-structured atmosphere, people tend to group in a more random manner. Is there any type of pattern to this kind of grouping? Let's take a closer look at this question by using the computer to model human behavior at a party. NetLogo's "Party" model looks specifically at the question of grouping by gender at parties: why do groups tend to form that are mostly men, or mostly women? Do all the groups have about the same number of people? Do all the groups have about the same number of each sex? Let's say you are having a party and invited 150 people. You are wondering how people will gather together. Suppose 10 groups form at the party. How do you think they will group? Instead of asking 150 of your closest friends to gather and randomly group, let's have the computer simulate this situation for us. Now how many people are in each group? Originally, you may have thought 150 people splitting into 10 groups, would result in about 15 people in each group. From the model, we see that people did not divide up evenly into the 10 groups. Instead, some groups became very small, whereas other groups became very large. Also, the party changed over time from all mixed groups of men and women to all single-sex groups. What could explain this?

There are lots of possible answers to this question about what happens at real parties. The designer of this simulation thought that groups at parties don't just form randomly. The groups are determined by how the individuals at the party behave. The designer chose to focus on a particular variable, called "tolerance": Tolerance is defined here as the percentage of people of the opposite sex an individual is "comfortable" with. If the individual is in a group that has a higher percentage of people of the opposite sex than their tolerance allows, then they become "uncomfortable" and leave the group to find another group. For example, if the tolerance level is set at 25%, then males are only "comfortable" in groups that are less than 25% female, and females are only "comfortable" in groups that are less than 25% male. As individuals become "uncomfortable" and leave groups, they move into new groups, which may cause some people in that group to become "uncomfortable" in turn. This chain reaction continues until everyone at the party is "comfortable" in their group. "Tolerance" in not fixed, user can move it from 1% to 99%. This leads to make some challenges. As the host of the party, you would like to see both men and women mingling within the groups. Adjust the tolerance slider on the side of the view to get all groups to be mixed as an end result. To make sure all groups of 10 have both sexes, at what level should we set the tolerance? Can you see any other factors or variables that might affect the male to female ratio within each group? As you are testing your hypotheses, you will notice that patterns are emerging from the data. For example, if you keep the number of people at the party constant but gradually increase the tolerance level, more mixed groups appear. How high does the tolerance value have to be before you get mixed groups? What percent tolerance tends to produce what percentage of mixing?

Using NetLogo to model a situation like a party allows you to experiment with a system in a rapid and flexible way that would be difficult to do in the real world. Modeling also gives you the opportunity to observe a situation or circumstance with less prejudice, as you can examine the underlying dynamics of a situation. You may find that as you model more and more, many of your preconceived ideas about various phenomena will be challenged. For example, a surprising result of the Party model is that even if tolerance is relatively high, a great deal of separation between the sexes occurs.

Chapter 6

Simulation for knowledge and export

I will drive you in the path I walked to reach solid and clear results. I will show and explain different level of my program, how I reach final model building it by various steps. How I *emerged to gaze upon the stars again*. It is time to define my programming plan. To understand, it is important to make clear what is matter in the model. Agents are Nations. They move, they change color and size. Movements describe where nations are going, color is associated to the technological position, size is associated to dimension of nations.

6.1 Level 0

The first level is my starting point, a simple model where building initial foundations. In order to have a solid building, foundations are very important. Foundations are basis for centerpieces. These centerpieces are not visible once the building is done and does not affect the exterior beauty. But still are frame, and must be a solid frame. That was the same for my job. A false step at this level, or a bad decision in which kind of formulas, or extensions, to use could compromise all stability and robustness of my model. I had already my own ideas, but the main difficulty was to draw all ideas in command lines. The first step is to build a starting point, called "Setup". Here I have written the basic structure of the model. In the level 0, I set the structure which agents have with an initial matrix. This initial matrix has a 4x1 structure. I consider rows as sectors with growing level of technology, chosen random by program. NetLogo considers first sector the sector 0, so why I let sector 0 and not 1.

```
set structure matrix:from-column-list [[0 0 0 0]]
let sector 0
        while [sector < 4 ]
        [matrix:set structure sector 0 1 + random-float 99
        set sector sector + 1]
```

These commands represent structure, let every four sector (writing "while [sector $<$ 4]") to have a random value among 1 and 100. This value represents, up to now, just how many workers there are in a specific sector. In other words, system gives a random value among 0 and 100 at the first sector, another random value among 0 and 100 at the second sector, and so on for the third and the fourth. The actual key to interpretation is the following: if a nation has a low value especially in the first and in the second sector, this nation has more workers occupied in production with low level of technology. If a nation has an high level in the third and especially

in the fourth sector, this nation has more workers occupied in production with a high level of technology. But this lecture will change soon. I show now another important part of "Setup", introducing a theoretical and graphical supplement: technological position. A nation with high sectors 3 and 4 has a higher technological position. A nation with high 1 and 2 sectors has a lower technological position. This is evident in figure 6.1 and in figure 6.2

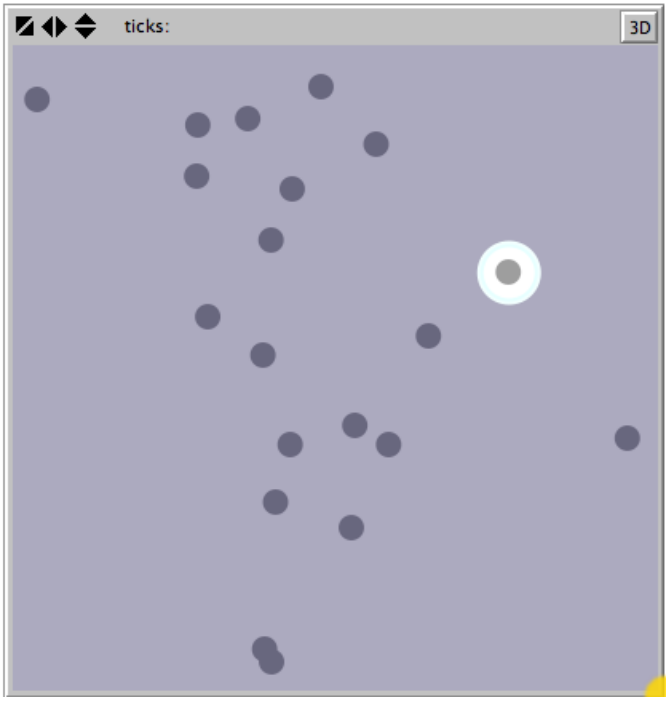


Figure 6.1: turtle 17

Turtle 17 has this structure

```
[ 5.681818181818182 ]
[ 8.522727272727273 ]
[ 32.38636363636363 ]
[ 53.40909090909091 ]
```

and technological position: 3.3352272727272725

Turtle 19 has this structure

```
[ 45.40816326530612 ]
[ 25 ]
[ 28.06122448979592 ]
[ 1.530612244897959 ]
```

and technological position: 1.8571428571428572

Matrix is obtained with commands written above. Technological position is the weighted average of four sectors, taking value of a sector and dividing it for 100, that is the sum of the four sector (because sum is a percentage). The maximum value is 4, the minimum value is 1. It means that if technological position takes value 4, its production is only in the fourth

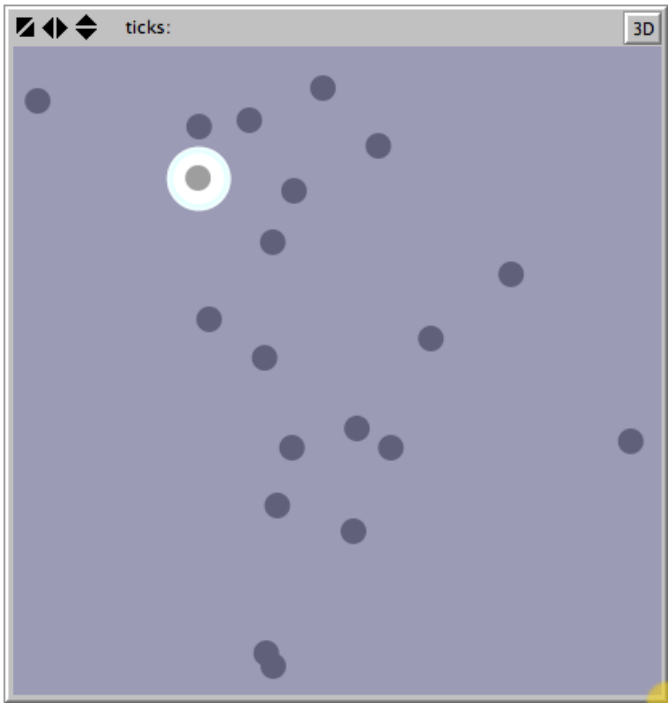


Figure 6.2: turtle 19

sector (the sector with higher level of technology), instead if technological position takes value 1, its production is only in the first sector (the sector with lower level of technology). Looking at the previous example of turtle 17 and turtle 19, we see that turtle 17 has a higher level of technological position respect to turtle 19.

```
to setup-technologicalPosition

 ask turtles
[
        let sector 0
        let tot 0
        while [sector < 4]
        [set tot tot + matrix:get structure sector 0
         set sector sector + 1]

        set sector 0
        set technologicalPosition 0

        while [sector < 4]
        [matrix:set structure sector 0 100 * matrix:get structure sector 0 / tot
                  set technologicalPosition
                  technologicalPosition +
                   (sector + 1) * (matrix:get structure sector 0 / 100 )
        set sector sector + 1]
```

```
        set xcor (technologicalPosition - 1) * 33
]
end
```

This part of the code is important for two reasons: first because tells, with a graphic point of view as seen above, nations with more workers in the more technological sectors. Second because now matrix "structure" represents how many workers are employed in a sector, with basis 100. If a nation have 50 in a sector means that 50 workers upon 100 are employed in the sector. In the "go" procedure it is possible to see how nations interact and how their level of productivity and technological position change. This last element is the one which received more modifications. It is important because we see now dynamics, no more a static world.

```
to technological-position

ask turtles
 [if knowledge >= 0
     [
        let sector 0
        while [sector < 3]
        [matrix:set changes sector 0

        matrix:get structure sector 0 *
        transitionEffect *
        knowledge

        set sector sector + 1]

        set sector 0
        while [sector < 3]
        [matrix:set structure (sector + 1) 0

         matrix:get structure (sector + 1) 0 +
         matrix:get changes sector 0

         matrix:set  structure  sector  0

         matrix:get structure  sector  0 -
         matrix:get changes sector 0

         set sector sector + 1]
      ]

  if knowledge < 0
     [
        let sector 3

        while [sector > 0]
        [matrix:set changes sector 0
```

```
        matrix:get structure sector 0 *
        transitionEffect *
        knowledge

        set sector sector - 1]

        set sector 3
        while [sector > 0]
        [matrix:set structure sector        0

        matrix:get structure  sector      0 +
        matrix:get changes sector 0

        matrix:set structure (sector - 1)  0

        matrix:get structure (sector - 1) 0 -
        matrix:get changes sector 0

        set sector sector - 1]
     ]


    let sector 0
    set technologicalPosition 0
    while [sector < 4]
     [set technologicalPosition technologicalPosition + (sector + 1) *
                                        matrix:get structure sector 0 / 100
      set sector sector + 1]


    set oldXcor xcor
    set xcor (technologicalPosition - 1) * 33
    if xcor >=  oldXcor [set color green]
    if xcor < oldXcor [set color red]

 ]
end
```

We see a new matrix "changes". This matrix has 4x1 dimension, the same size of other matrices used in this model and it is useful to modify matrix "structure" with my basic idea: knowledge is the driver. As seen above, knowledge assumes a random value from -0.5 to 0.5. Matrix "changes" is the result of a multiplication of "structure", knowledge and transition effect. Transition effect is a boosting variable. Matrix "changes" modifies values of matrix structure, and it is the way how knowledge influences structure. If knowledge is positive, quotas in matrix structure moves from the first sector to the second sector. This value is subtracted from the first sector and added to the second sector, and so on for all four sectors. With a code so modeled, regarding part with positive knowledge, every tick (tick is for NetLogo the increase of one unit of time) increases value in the more technological sectors. It means more workers in more technological sectors, according to my fundamental idea, more high-level knowledge production. Conversely, if knowledge is negative, quotas in matrix structure tend to move to

sectors with lower technology, because workers lose knowledge and technological sectors lose their technological productive drive.

Negative knowledge Does negative knowledge makes sense? Let imagine a nation that, for exogenous reasons, does not invest in schooling, in research and development, in university. This nation will have a depletion of knowledge widespread in its citizens, and year after year will not be anymore able to produce some products requiring some specific knowledge because that knowledge has been lost. In HH view of product space like a "forest", the nation has lost a "tree".

Variable "technologicalPosition" assumes a figurative meaning, making visible the position regarding technological level of production (remember basic assumption: high technological production means high knowledge level). When nations move to the left, it means that knowledge influences negatively matrix structure and presence of workers is becoming higher in sectors with low technology level, but also means that presence of workers is becoming lower in sector with high technological level. It is possible to recognize these nations, because nations with a situation above described are distinguishable by the red color. Vice versa nations which tend to increase workers in higher technological sectors are identifiable by green color. Movements described are on x-axis. Now we see what happen on the y-axis, starting from the setup of productivity.

```
to setup-productivity

ask turtles

[let sector 0

       while [sector < 4]
        [matrix:set productivity sector 0  1 + random-float 99
          set sector sector + 1]

    set sector 0
    set productivityPosition 0

    while [sector < 4]
    [ set productivityPosition productivityPosition +
      (matrix:get productivity sector 0 * matrix:get structure sector 0 )
      / 100
      set sector sector + 1]

        set ycor productivityPosition
]
end
```

I started giving a value of productivity to every sector. Productivity is the efficiency in production of a good or many goods, measured in terms of the rate of output per unit of input. At this level, it means basically the output per worker, given randomly from 1 to 99. Then, this matrix is multiplied with the corresponding sector of the matrix "structure". Recalling what said before, "structure" represents the quantity of workers in every of the four sectors. The result of every sector is then summed to obtain a single value by which is possible to place the nation along the y-axis. The more a nation is near high side, the more this nation has an high level of productivity. The more a nation is near to the low side, the lower is the level of productivity

for a nation. The division by 100 is a mathematical adjustment to have a better graph. After the setup of the productivity, we proceed analyzing a procedure called "productivity-position". I have introduced two new exogenous variables, "efficiency-invest-in-know" and "effect-of-invest". We can easily think that every nation, even the less rich, invest some money in improving their level of knowledge. But as every kind of investment, also investment in knowledge has a certain level of efficiency. I do not discuss about the causes, i just use this result to weight the effect of knowledge. It is a simplistic implementation, and it can be one of the argument to improve in other thesis, but not implement it could be a bigger mistake. We have now understood what is "efficiency-invest-in-know". The second variable, "effect-of-invest", is the multiplication of knowledge and efficiency of investment in knowledge. This second variable is the one that influences productivity. If knowledge is positive, productivity increases, if knowledge is negative, productivity slows down. It is different from the procedure seen before about technological position, because level of productivity in a sector is not tied to other sectors. A nation may have a sector with very high productivity even if productivity in other sectors is very low.

```
to productivity-position
ask turtles
[set effect_of_invest
   (knowledge * efficiency_invest_in_know)]
   ask turtles

   [if knowledge >= 0

     [ let sector 0

        while [sector < 4]
        [matrix:set productivity sector 0  matrix:get productivity sector 0  +
                                              effect_of_invest
        set sector sector + 1]  ]


  if knowledge < 0

     [ let sector 0

        while [sector < 4]
        [matrix:set productivity sector 0  matrix:get productivity sector 0 -
                                            (- effect_of_invest)
        set sector sector + 1]]

    let sector 0
    set productivityPosition 0
           while [sector < 4]
    [ set productivityPosition productivityposition +
      (matrix:get productivity sector 0 * matrix:get structure sector 0) / 100
      set sector sector + 1]

    if productivityPosition <= 0 [set productivityPosition 0.1 ]
    if productivityPosition > 100 [set productivityPosition 99 ]
```

```
    set ycor productivityPosition
   ]

end
```

We see now a basic idea for import and export. From Smith, we know that nations trade when productivity is low in a sector, importing goods produced in sector with low productivity, specializing where productivity is higher than the other nations and exporting goods produced in these sectors. Trade arises from necessity of nations with lower productivity in specific sectors, so importers nations create links to the exporters nations (with high productivity). Level of productivity is fixed in this version. If a nation has productivity lower than 20 in a sector, it asks to nations with productivity higher than 80 in the same sector to import goods.

```
to go-links

  clear-links

  ask turtles
   [let sector 0
     if matrix:get productivity sector 0 < 20
     [while [sector < 3]
     [create-links-to other turtles with

       [matrix:get productivity sector 0 > 80]
       set sector sector + 1]]]

end
```

We can see in the figure 6.3 a graphic example of the previous code.

6.2 Level 1

Level 0 was basically to set the starting point, the centerpiece. I want to focus on analyzing interactions among nations. To reach this result, I need to introduce relevant parts of code. It may be seem just a little part of code, but it is the basis to introduce the evidence of absolute advantages. It the part of the code called "size-of-nations" I have introduced another discriminating factor for nations.

```
to size-of-nations

   ask turtles
[
  let setsize 1
 let sector 0
 while [sector < 4]

[set setsize setsize + (matrix:get structure sector 0 * (sector + 1) )  / 100
        set sector sector + 1]
```

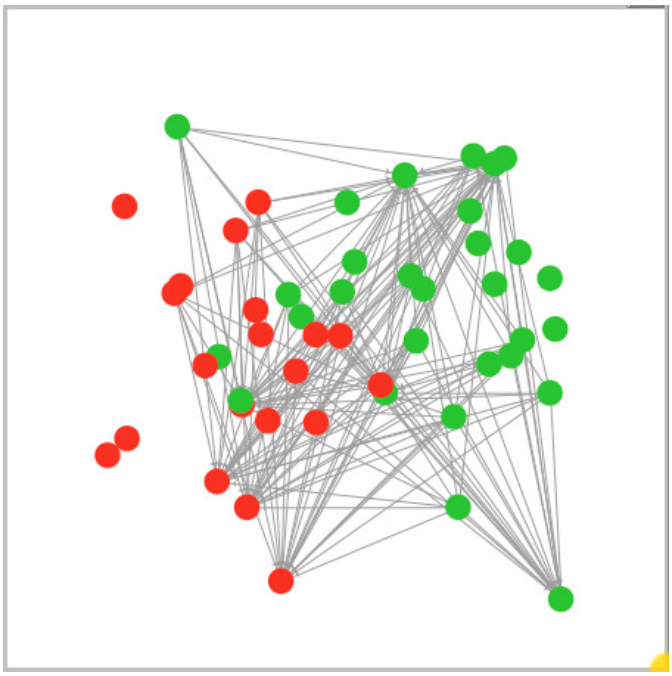


Figure 6.3: Level 1

```
set size setsize]

end
```

I make the size depending on the sum of the values in the matrix "structure". Recalling from level 0, structure tells how many workers are inside every sector. A nation is bigger when has more workers, but also depending in which sector they are. Therefore actually size depends on how many workers there are in a nation, but the amount in every sector is multiplied for the sector following. This is to weight the sector where workers are. If we take two nations (A and B), with same number of workers but nation A has the majority of them in the lowest sector while nation B has the same amount in the most technological sector, the nation B will be bigger than nation A.

```
to go-links

  clear-links

  ask turtles
   [let sector 0
     if matrix:get productivity sector 0 > threshold_productivity_exporter
     [while [sector < 3]
     [create-links-to other turtles with

       [matrix:get productivity sector 0 < threshold_productivity_importer]
```

```
      set sector sector + 1]]]

end
```

Here we have a change respect to level 0. Now a nation can decide to export or import depending on its amount of productivity. If nation A has a level of productivity higher than 50, it becomes a potential exporter. If its productivity is lower than 50, it becomes a potential importer. While in the previous level the threshold was fixed by the developer, now there are are two sliders called "threshold productivity exporter" and "threshold productivity importer". A nation is available to create a link if its level of productivity in a sector is higher than the threshold for the exporters. The nation creates a link if the other nation has a productivity lower than the threshold for the importers.

6.3 Level 2

In the level 2 we see a hugh improvement in the model, with the differentiation between absolute advantages and a basic - but structurally important - foundation of comparative advantages. About absolute advantages, we saw in the previous level how they work. The code is fundamentally the same, with comparison between productivities in different sectors. If nations create the link, is means there is exchange. The difference with level 1 is more conceptual: nations decide to import to satisfy a need. With this view, the nation with a productivity low is the one who is candidate to create a link with nations with high productivity.

```
to absolute-advantage

  clear-links

  ask turtles
   [let sector 0
     if matrix:get productivity sector 0 < threshold_productivity_importer
     [while [sector < 4]
     [create-links-to other turtles with
     [matrix:get productivity sector 0 > threshold_productivity_exporter]
      set sector sector + 1]]]

links-import

size-of-nations

technological-position

productivity-position

plot-link

end
```

Every unit of time, nations are asked to evaluate if the link can be activated again, if conditions are satisfied. It means that every unit of time previous links are erased with the command “clear-links”.

The part of code that is completely new is the following:

```
 ask turtles
   [create-links-to other turtles ]


ask links [   ;p1Vp2

  if
     [matrix:get productivity 0 0] of (end1) > [matrix:get productivity 0 0] of (end2)
   and
     [matrix:get productivity 1 0] of (end1) < [matrix:get productivity 1 0] of (end2)

  [ask end1
       [matrix:set labour-quota 0 0
        matrix:get labour-quota 0 0 + shift-labour-quota
        matrix:set labour-quota 1 0
        matrix:get labour-quota 1 0 - shift-labour-quota

    set status "yesimport1" ]

  ask end2
      [matrix:set labour-quota 1 0
       matrix:get labour-quota 1 0 + shift-labour-quota
       matrix:set labour-quota 0 0
       matrix:get labour-quota 0 0 - shift-labour-quota

   set status "yesimport2"] ]

ask links with [[status] of end1 != "yesimport1"] [die]
ask links with [[status] of end2 != "yesimport2"] [die]
]
```

This is the fundamental code for comparative advantages. Nations create a link with all other nations. Then they compare productivity in two sector for each couple of nations. An example: nation A (end1) has a productivity in the first sector higher than productivity in the same sector of nation B, but the productivity in the second sector of nation A is lower than productivity in the second sector of nation B. This link is named "yesimport". Every link without this name “dies”, leaving active only links with the name.

6.4 Final level

This level takes the final code useful leading to the experiments. Some strings are renamed, for example substituting the “yesimport” with a more specific term for each link. Other technical

part are changed. The shift is no more on labour quota in every sector, now workers move sectors. This is to make more realistic the model. The comparison is between the productivity of two sectors of two nations. In the code written below we see an example: the ratio between productivity of sector 0 in nation A and productivity of sector 0 in nation B is lower than the ratio between productivity of sector 1 in nation A and productivity of sector 1 in nation B. In this case nation A (end1) has a comparative advantage to produce in sector 1, while nation B (end2) has a comparative advantage to produce in sector 0. Because nation A (end1) has a comparative advantage to produce in sector 1, workers will shift from sector 0 to sector 1. In the nation B (end2) happens the opposite: workers will shift from sector 1 to sector 0. The two variable "inc-dif" (increasing difference) and "red-dif" (reducing difference) improve or reduce value of the ratio, to avoid that small differences influence behavior of nations. The code described is the following:

```
to  p1Vp2-CA-with-effect

ask links
[ifelse
[matrix:get productivity 0 0] of (end1) /
[matrix:get productivity 0 0] of (end2) * inc-dif
   <
[matrix:get productivity 1 0] of (end1) /
[matrix:get productivity 1 0] of (end2) * red-dif

  [ask end1
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 + shift-workers]
  ask end2
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 + shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers]

 ask end1
 [ask out-link-to other-end [set status01 ‘‘1-0’’]

 ask in-link-from other-end [show-link]]]]
```

In the same procedure there is the opposite case. The ratio between productivity of sector 0 in nation A and productivity of sector 0 in nation B is higher than the ratio between productivity of sector 1 in nation A and productivity of sector 1 in nation B. In this case nation A (end1) has a comparative advantage to produce in sector 0, while nation B (end2) has a comparative advantage to produce in sector 1. Because nation A (end1) has a comparative advantage to produce in sector 0, workers will shift from sector 1 to sector 0. In the nation B (end2) happens the opposite: workers will shift from sector 0 to sector 1.

```
[if
```

```
[matrix:get productivity 0 0] of (end1) /
[matrix:get productivity 0 0] of (end2) * red-dif
    >
[matrix:get productivity 1 0] of (end1) /
[matrix:get productivity 1 0] of (end2) * inc-dif

  [ask end1
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 + shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers]
  ask end2
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 + shift-workers]

  ask end1
    [ask out-link-to other-end [set status01 ``0-1''']

    ask in-link-from other-end [show-link]]]]]
```

The variable status01 is a feature of links. Analyzing the information inside the link, we are able to understand in which way comparative advantages appear. In the case above, if the link shows "1-0" we know that nation A has a comparative advantage in sector 1 and nation B has a comparative advantage in sector 0. If the link shows "0-1", we know that nation A has a comparative advantage in sector 0 and nation B has a comparative advantage in sector 1. Moreover, another improvement has been the differentiation between comparative advantages with effect on the shift of the workers and comparative advantages without effect on the shift of the workers. In comparative advantages without effect, we see just the ratio, but without shift of workers. This differentiation is important to understand the sense of HH's research, and how comparative advantages theory should be abandoned in favor of an economy based seriously on knowledge. Full code is displayed in Appendix .2.

6.5 Further extensions

In this work I used intensively my developed model. I like to think about it as a basis to motivate and drive policy action in favor of a more attention regarding knowledge: starting from government and private investments, going through the importance devoted to knowledge that persons should have for themselves and for their nations, coming to the care for efficient schools and universities. Moreover, it can become a much better tool with the integration in the model of real economic and trade values. Analyzing data from other researches, an example is the introduction of real values about technological sectors, level of knowledge and productivity, and how real parameters influences internal growth.

Chapter 7

Scenarios and experiments

7.1 Description of scenarios

Scenario A Number of agents (countries): 28, as in figure 7.1
Countries are divided in four groups.

1) The first seven have an high quota of workers (around 80%) in the less technological sector and this sector is very productive. The other sectors have a little quota of workers and are very low productive.

2) The second group has the majority of workers in the second and in the third sector. The quota on workers in this two sector is 80%, and are very productive. The first and the fourth sector have a low quota of workers and are very low productive.

3) The third group has a similar distribution of workers, around 20-30% each sector, and productivity is similar.

4) The fourth group is symmetrical to the first group. This group has an high quota of workers (around 80%) in the most technological sector and this sector is very productive. The other sectors have a low quota of workers and low productivity

Scenario B Number of agents (countries): 28, as in figure 7.2
Countries are divided in four groups.
From the point of view of the distribution of workers among sectors, this scenario is very similar to the previous scenario 1, but in this kind of world every sector has a very low productivity.

1) The first eight have an high quota of workers (around 80%) in the less technological sector. The other sectors have a little quota of workers.

2) The second group has the majority of workers in the second and in the third sector. The quota on workers in this two sector is 80%. The first and the fourth sector have a low quota of workers.

3) The third group has a similar distribution of workers, around 20-30% each sector.

4) The fourth group has is symmetrical to the first group. This group has an high quota of workers (around 80%) in the most technological sector. The other sectors have a low quota of workers.

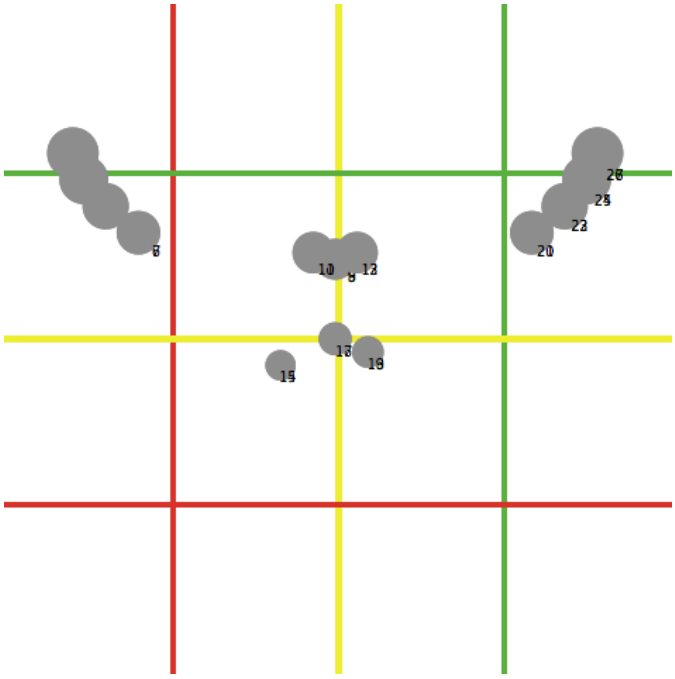


Figure 7.1: Scenario A - starting point

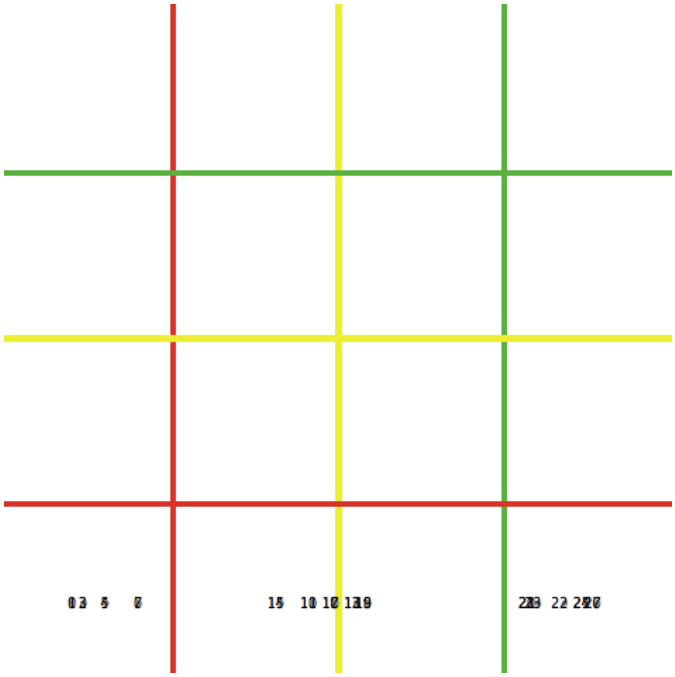


Figure 7.2: Scenario B - starting point

Scenario C Number of agents (countries): 24, as in figure 7.3

This scenario is unrealistic, but it useful to understand dynamics for similar agents with different dimensions. This scenario has four groups.

1) The first six have an high quota of workers (60%) in the less technological sector. The other sectors have a little quota of workers. Productivity is high, more than 80% for all sectors. The difference is only in bigness of agents, the first two are two times bigger than the agents two and three and six times bigger than agent four and five.

2) The second group has the quota of workers and dimension as previous group, but productivity is very low, less than 20.

3) The third group has an high quota in workers (60%) in the most technological sector, productivity is low and dimension follows the rule of first group.

4) The fourth group has quota of workers and dimension as previous group, but productivity is very high, more than 80, for all agents of this group.

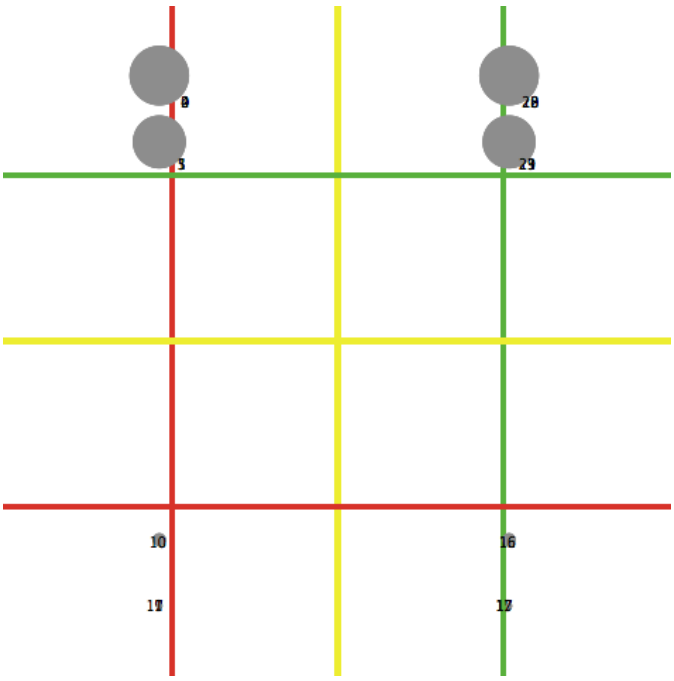


Figure 7.3: Scenario C - starting point

Scenario D Number of agents (countries): 21, as in figure 7.4

This is a counterfactual scenario: countries are fundamentally divided in three groups corresponding to different level of workers among sectors. Productivity is the same for all countries, and it is 90 for the first sector (the less technological one), 80 for the second sector, 20 for the third sector and 10 for the fourth sector (the most technological one).

1) The first eight have an high quota of workers (more than 50%) in the less technological sector. The other sectors have a little quota of workers.

2) The second group has a balanced quota of workers in all four sector, from 20% to 45%.

3) The third group of 5 agents has high quota of workers in the fourth sector (more than 50%), while the other sectors are less than 20%.

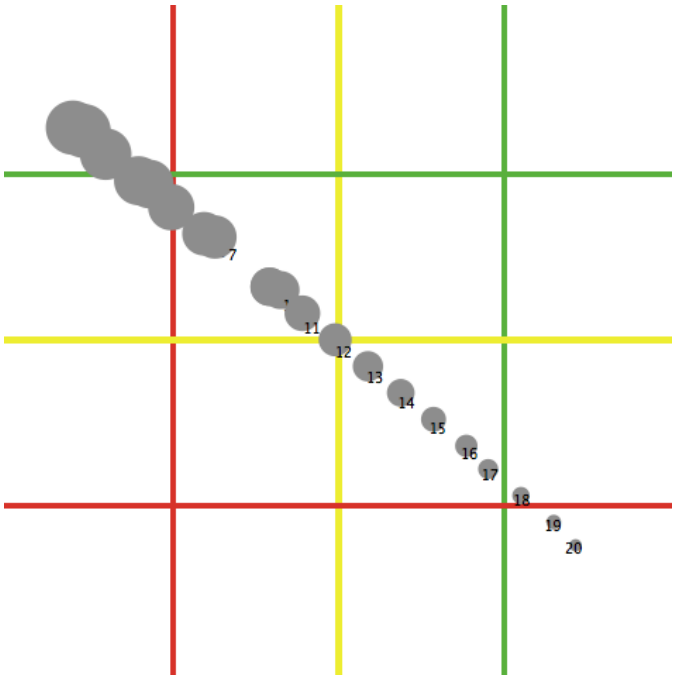


Figure 7.4: Scenario D - starting point

Scenarios E and F Number of agents (countries): 21, as in figure 7.5 and as in figure 7.6

These two scenarios are opposite respect to scenario D, and are the two more corresponding to the real world. Productivity is the same for all countries, and it is 10 for the first sector (the less technological), 20 for the second, 80 for the third and 90 for the fourth (the most technological)

1) The first eights have an high quota of workers (more than 50%) in the fourth, most technological sector. The other sectors have a little quota of workers.

2) The second group has a balanced quota of workers in all four sector, from 20% to 45%.

3) The third group of 5 agents has high quota of workers in the first sector (more than 50%) that is the less technological, while the other sectors are less than 20%.

The difference between scenario E and scenario F is knowledge. In both scenarios nations with green color start with positive knowledge and nations with red color start with negative knowledge, but in scenario E nations with higher technology and productivity have also a positive knowledge, while in scenario F nations with higher technology and productivity start with negative knowledge.

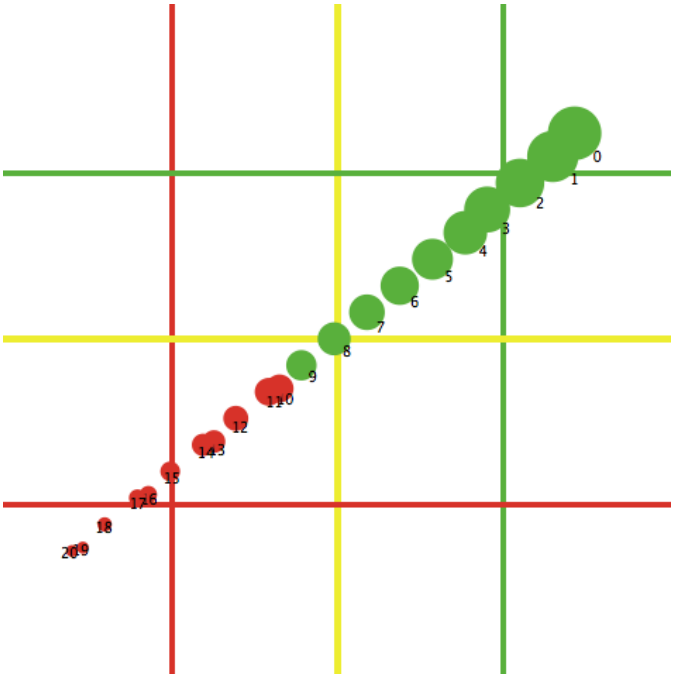


Figure 7.5: Scenario E - starting point

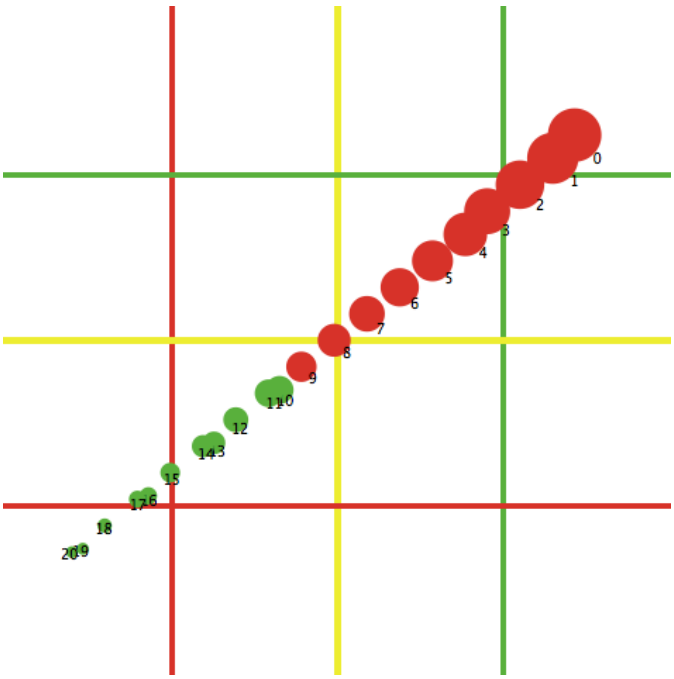


Figure 7.6: Scenario F - starting point

7.2 Description of experiments: CA with effects on workers' quota

In the following paragraph I will briefly introduce the experiments. Every scenario seen above will be tested in the following experiments.
For high efficiency of investment in knowledge, it means this parameter is 0.95. If it is low, the parameter is 0.05.
For high shift of workers, the parameter is 0.9. If it is low, the parameter is 0.1.

Experiment 1

1) Efficiency of investment in knowledge: high

2) Shift of workers: high

Experiment 2

1) Efficiency of investment in knowledge: low

2) Shift of workers: high

Experiment 3

1) Efficiency of investment in knowledge: high

3) Shift of workers: low

Experiment 4

1) Efficiency of investment in knowledge: low

2) Shift of workers: low

7.2.1 Experiments on CA with effect on workers' quota

Scenario A - Experiment 1

Description and waited result:

- I wait some nations change their position, according to their positive or negative knowledge
- I wait that nations in the middle of the screen don't move so much, thank to their balanced productivity
- I wait that nations on the right could improve their technological position and move little more on the right
- I wait some nations fall on the left corner, because of negative knowledge

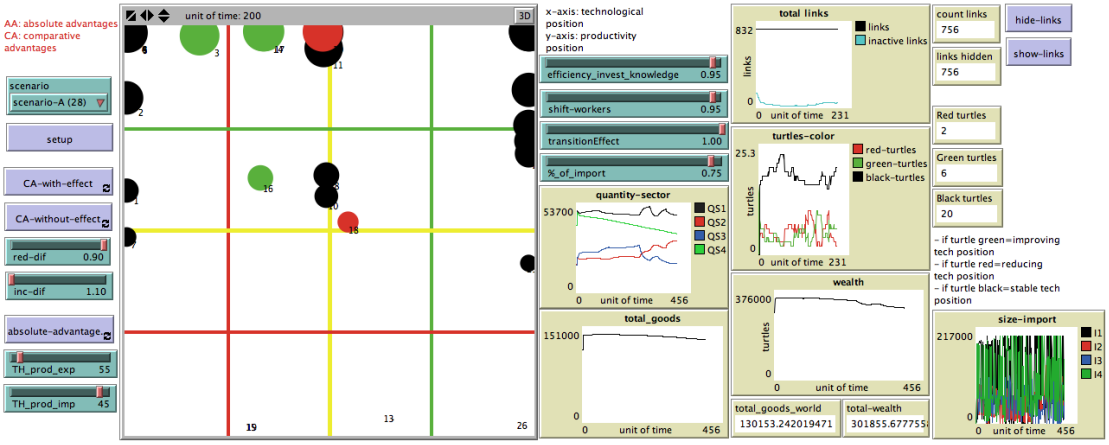


Figure 7.7: Experiment CA with effects - A1: result after 200 units of time

Results after 200 units of time (ticks):

- nations spread more than expected, especially those with negative knowledge
- negative knowledge influences more productivity than technology
- nations 3, 14, 17 and 16, which are around x-axis red line, are slowly improving their technological position, due to their positive but low level of knowledge

Scenario A - Experiment 2

Description and waited result:

- I wait few nations change their position, according to their positive or negative knowledge
- I wait that nations on the right could improve their technological position and move little more on the right, and the opposite for the left nations
- I wait that nations in the middle of the screen don't move so much, thanks to their balanced productivity

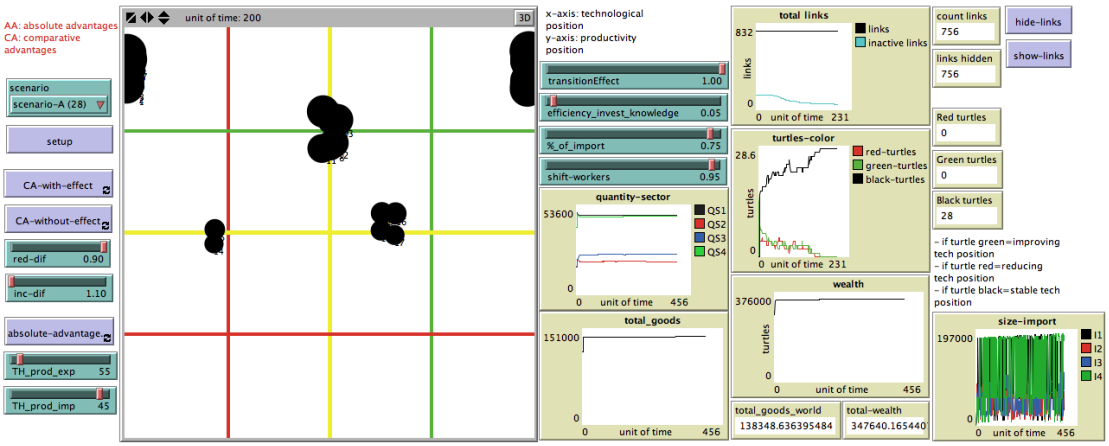


Figure 7.8: Experiment CA with effects - A2: result after 200 units of time

Results after 200 units of time (ticks):

- nations satisfy expected results
- nations in the middle quarter left worsen because of negative knowledge
- nations in the middle quarter right improved because of positive knowledge
- all nations reach a sort of steady-state

Scenario A - Experiment 3

Description and waited result:

- I wait many nations change their productivity position, according to their positive or negative knowledge
- I wait that nations with positive knowledge on the left could improve their technological position and move little more on the right, and the opposite for the right nations
- I wait that nations in the middle of the screen don't move so much, thanks to their balanced productivity

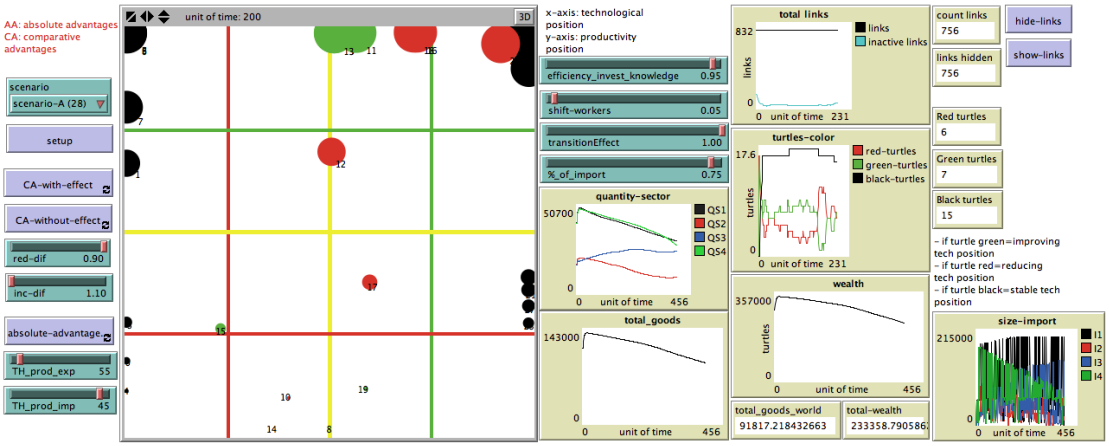


Figure 7.9: Experiment CA with effects - A3: result after 200 units of time

Results after 200 units of time (ticks):

- nations respect waited results
- nations spread all around, and with an high influence of knowledge on productivity. Many nations maintains their technological position, going to lose in term of productivity position

Scenario A - Experiment 4

Description and waited result:

- I wait low mobility, but nations with high or low level of knowledge will move
- I wait that nations in the middle of the interface will move from there

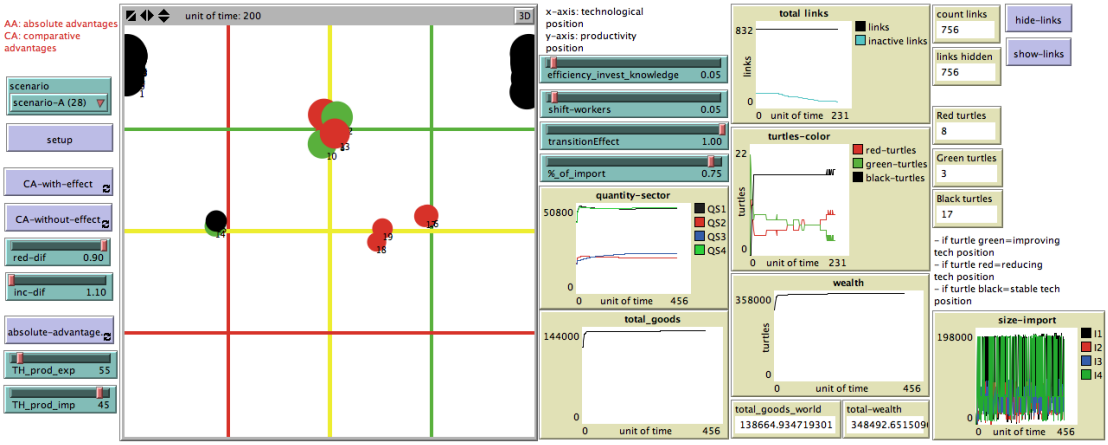


Figure 7.10: Experiment CA with effects - A4: result after 200 units of time

Results after 200 units of time (ticks):

- there is low mobility around the interface
- nations tend to stay around their starting position, because the effect of knowledge and competitive advantages is almost undoing each other
- surprisingly, nations in the middle are stable during all the experiment, because the effect of knowledge and competitive advantages clearly undoing

Scenario B - Experiment 1

Description and waited result:

- for nations with positive knowledge, I wait improvement both in technological and productivity position
- for nations with negative knowledge, I wait a small decrease in both position
- I wait an important movement but not many active links

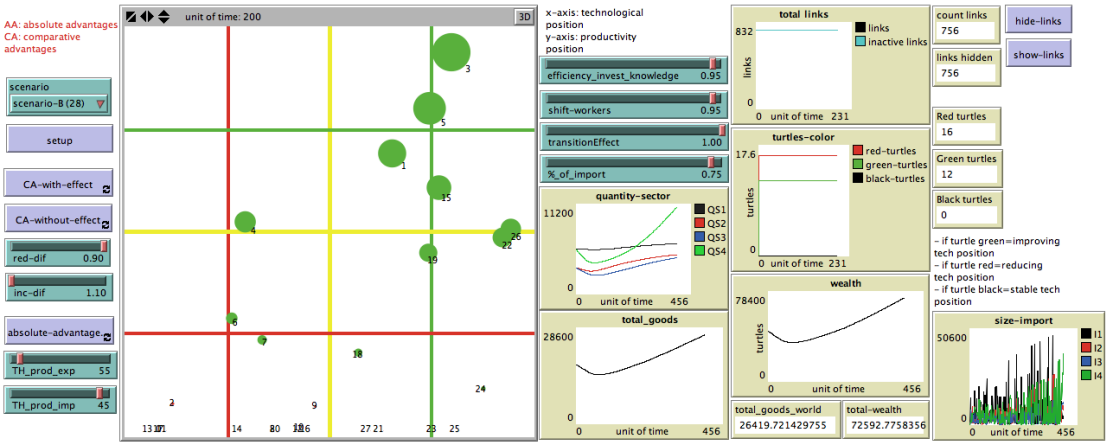


Figure 7.11: Experiment CA with effects - B1: result after 200 units of time

Results after 200 units of time (ticks):

- nations with positive knowledge improve in both position
- all links are inactive: no possibility of competitive advantages to take part of action. Nations increase and decrease their position because they see their advantage, even without exchange. It is the reason we see technological position change

Scenario B - Experiment 2

Description and waited result:

- I wait that knowledge interfere not enough, so productivity position should stay low for all nations
- on the other side, I wait movements on technological position

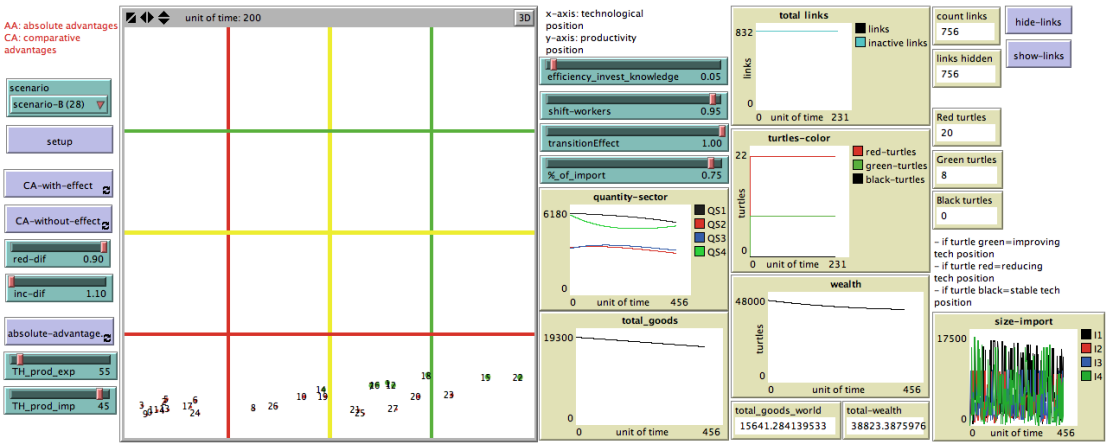


Figure 7.12: Experiment CA with effects - B2: result after 200 units of time

Results after 200 units of time (ticks):

- all nations stay in the low side of the interface, productivity position remains low for all
- there is a good movement on the technological position, caused by shift of workers. Nations see the advantage even if there is no exchange
- all links are inactive: no possibility of exchange to take part of action. Nations increase and decrease their position because they see their advantage, even without exchange. It is the reason we see technological position change

Scenario B - Experiment 3

Description and waited result:

- I wait results similar to the experiment 1, but with less effect due to low shift of workers

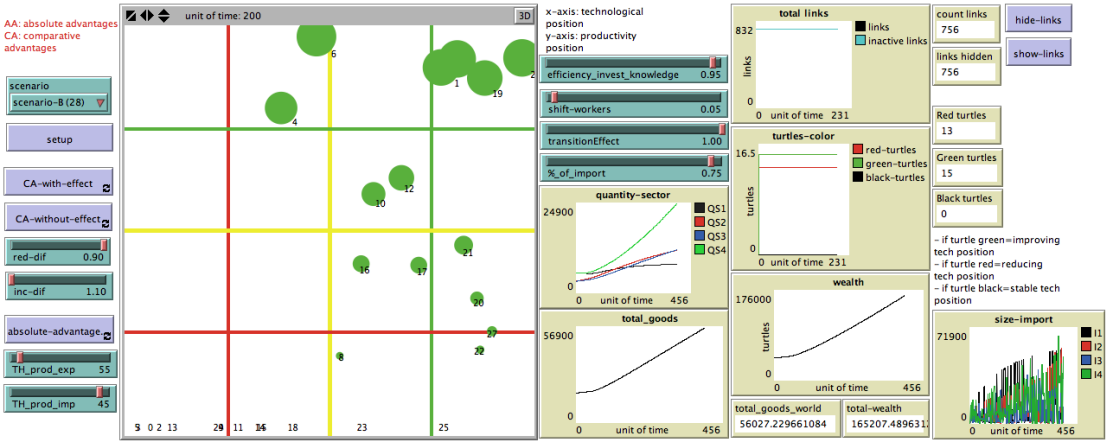


Figure 7.13: Experiment CA with effects - B3: result after 200 units of time

Results after 200 units of time (ticks):

- nations with positive knowledge improve in both position. Positive knowledge has a hugh impact on nations
- there is a good movement on the technological position, now caused by knowledge and not by shift of workers
- all links are inactive: no possibility of exchange to take part of action. Nations increase and decrease their position because they see their advantage, even without exchange. It is the reason we see technological position change

Scenario B - Experiment 4

Description and waited result:

- I wait that knowledge interfere not enough, so productivity position should stay low for all nations
- on the other side, I wait movements on technological position because of shift of workers

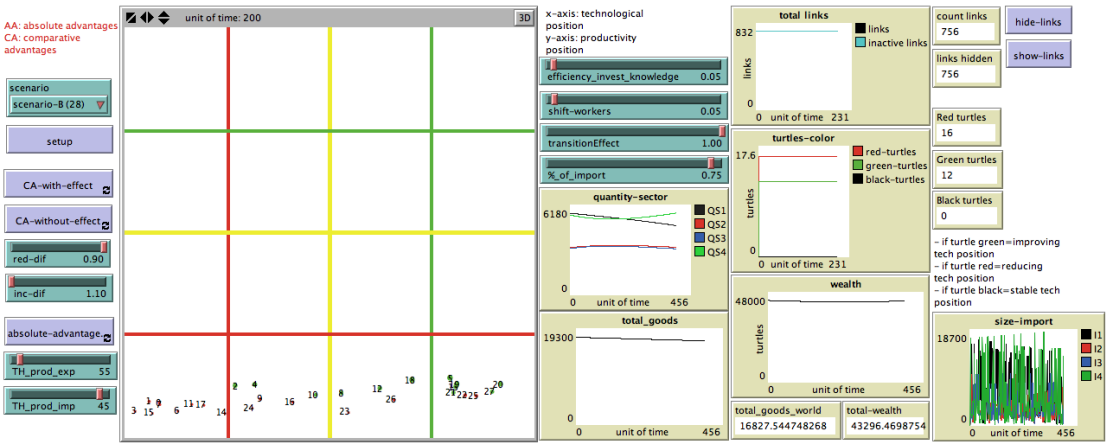


Figure 7.14: Experiment CA with effects - B4: result after 200 units of time

Results after 200 units of time (ticks):

- all nations stay in the low side of the interface, productivity position remains low for all
- there is a good movement on the technological position, but lower than experiment 2.
- all links are inactive: no possibility of exchange to take part of action. Nations increase and decrease their position because they see their advantage, even without exchange. It is the reason we see technological position change

Scenario C - Experiment 1

Description and waited result:

- a lot of movement, because of the very different level of starting productivity and workers in technological sectors
- knowledge should have effect both on productivity and technology
- I wait a positive number of active links

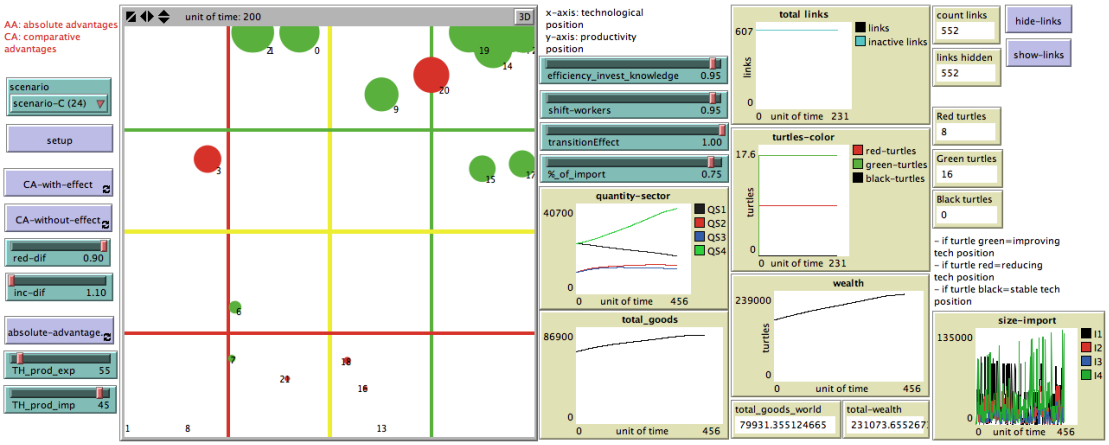


Figure 7.15: Experiment CA with effects - C1: result after 200 units of time

Results after 200 units of time (ticks):

- knowledge is the driver: nations with positive knowledge shifted to the high-right corner, while nations with negative knowledge moved to the low-left
- there is one exception: nation 20 has negative knowledge, but knowledge is very close to zero and it started from a very good position to move lower left
- all links are inactive: no possibility of exchange to take part of action. Nations increase and decrease their position because they see their advantage, even without exchange. It is the reason we see technological position change

Scenario C - Experiment 2

Description and waited result:

- I wait high movement on x-axis, not caused by knowledge but by effect of workers
- I wait few movement on y-axis, because of the reduced effect of knowledge

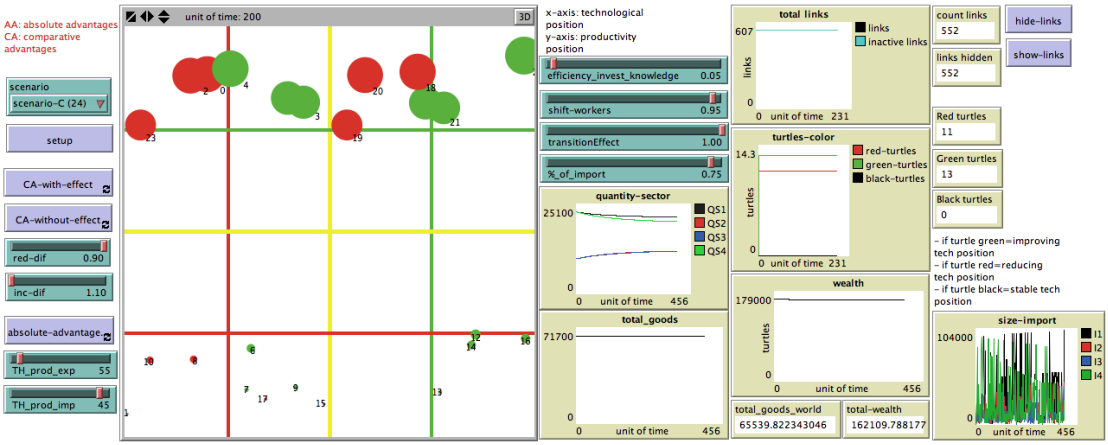


Figure 7.16: Experiment CA with effects - C2: result after 200 units of time

Results after 200 units of time (ticks):

- the model responds exactly as waited
- nations tend to move only horizontally and improve or decrease their technological position

Scenario C - Experiment 3

Description and waited result:

- I wait low movement on x-axis, caused by knowledge
- I wait high movement on y-axis, because of the increased effect of knowledge with respect to shift of workers

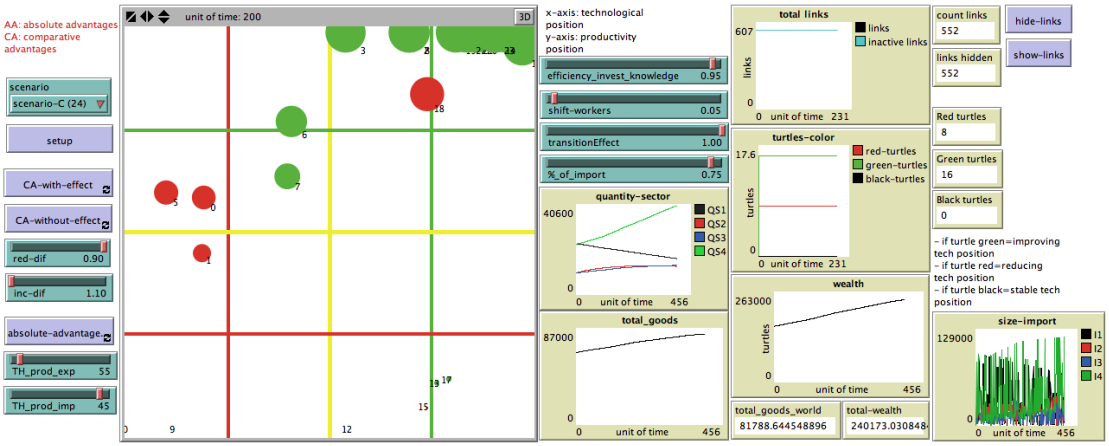


Figure 7.17: Experiment CA with effects - C3: result after 200 units of time

Results after 200 units of time (ticks):

- the model responds as waited
- nations move both on technological and productivity position, with a small prevalence for the second
- exception: nation 18 keeps initial position, owed to its good starting point despite a negative (but close to zero) knowledge

Scenario C - Experiment 4

Description and waited result:

- I wait same result of the second experiment, but with lower impact
- high movement on x-axis, not caused by knowledge but by effect of workers
- I wait few movement on y-axis, because of the reduced effect of knowledge

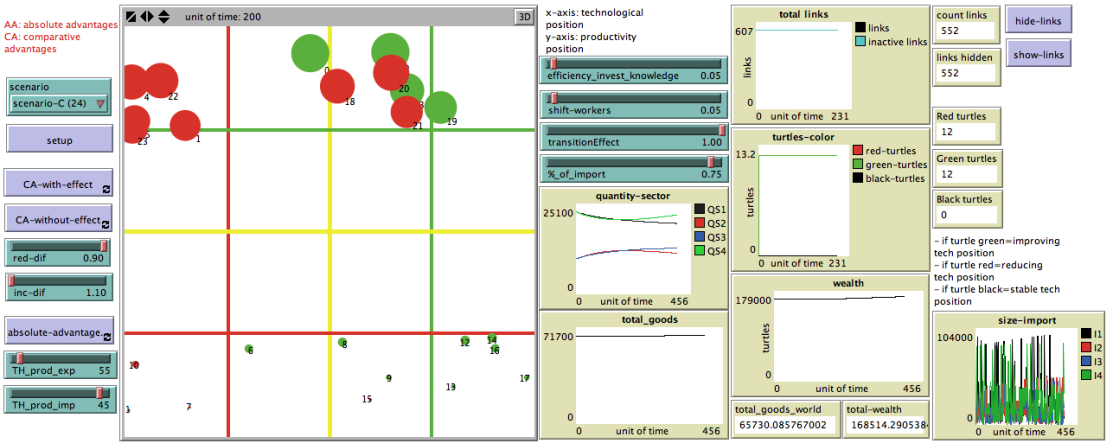


Figure 7.18: Experiment CA with effects - C4: result after 200 units of time

Results after 200 units of time (ticks):

- the model responds as waited, but with some exceptions
- movement on y-axis (productivity position) is negligible, great movement is on the x-axis (technological position)
- example of exception: nations 22 and 23 move from the right side to the left, owed to high negative knowledge

Scenario D - Experiment 1

Description and waited result:

- I wait hugh movement from all nations. I expect that nations on the left but with positive knowledge will improve their position going right and up
- I wait the opposite from nations with negative knowledge. The effect depends from the amount of knowledge

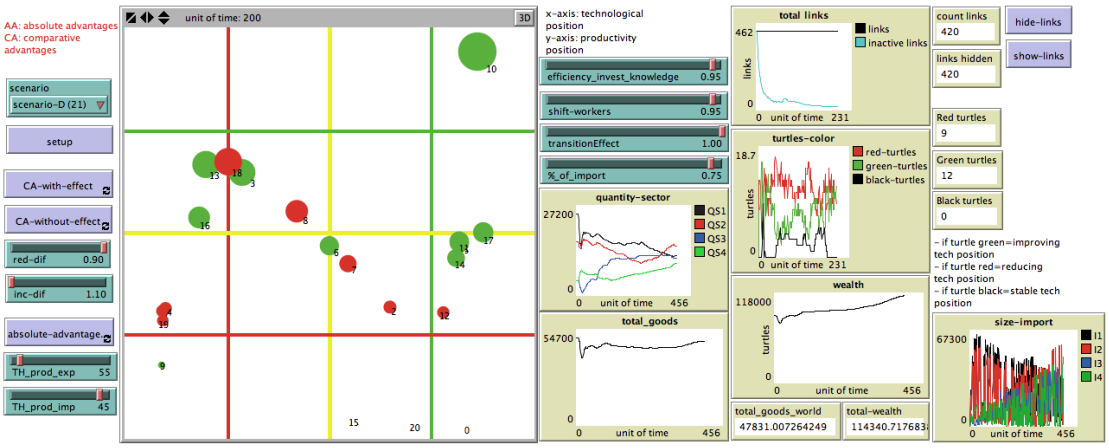


Figure 7.19: Experiment CA with effects - D1: result after 200 units of time

Results after 200 units of time (ticks):

- all nations at the beginning of the experiment moved, but after 200 units of time about ten nations come back around the starting point. The other ten spread around the world
- the ten nations that are back around starting point because a negative effect of knowledge, which does not allow them to increase in technological position

Scenario D - Experiment 2

Description and waited result:

- I wait low movement from all nations. I expect more movement in technological position
- in this experiment comparison in comparative advantages should make the difference in technological position

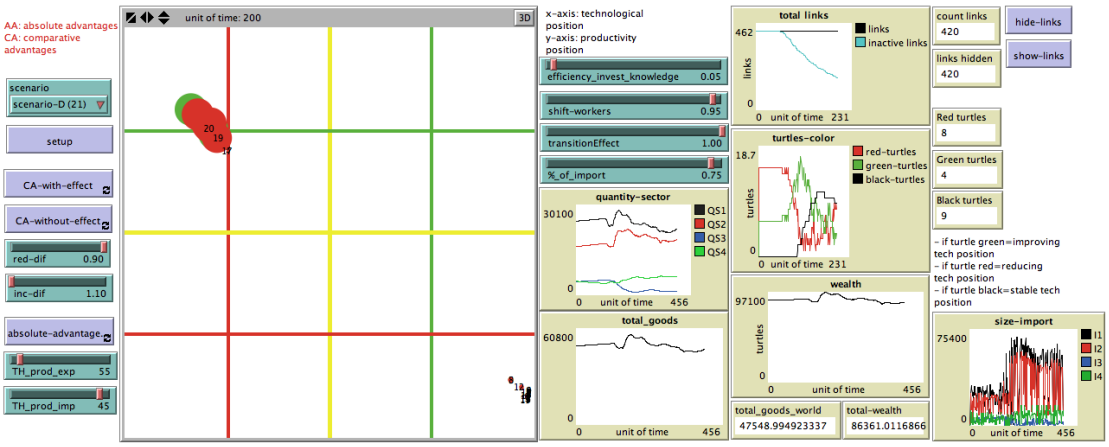


Figure 7.20: Experiment CA with effects - D2: result after 200 units of time

Results after 200 units of time (ticks):

- nations are divided in two groups: group on the left with high level of productivity but low level of workers in more technological sectors; group on the right with superiority of workers in high technological sectors but with low productivity
- this is owed to a low impact of knowledge, which does not allow to nations in improving productivity
- these observations are confirmed by quantity-sectors plot: production in sectors 1 and 2 is much higher than sectors 3 and 4

Scenario D - Experiment 3

Description and waited result:

- I wait lot of movement from all nations in productivity position
- in this experiment knowledge should not make the difference in technological position

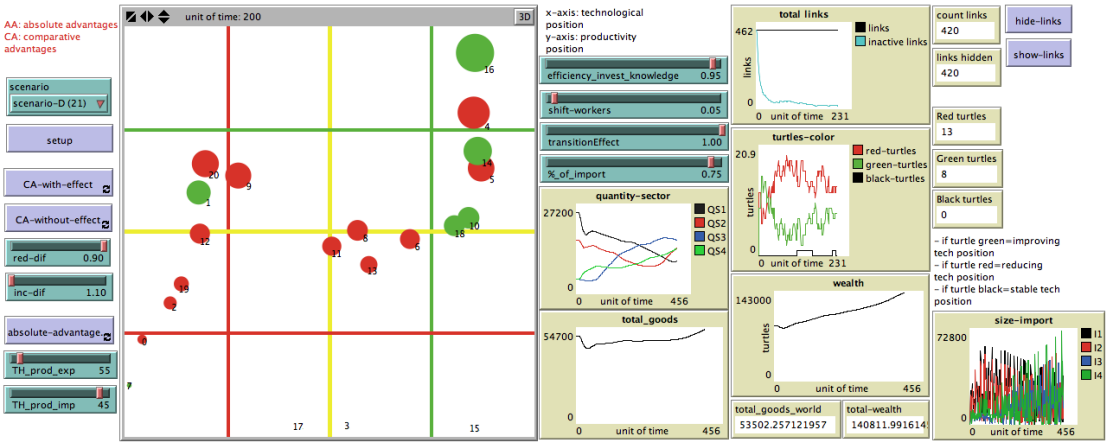


Figure 7.21: Experiment CA with effects - D3: result after 200 units of time

Results after 200 units of time (ticks):

- obtained results are not much similar to waited results
- nations spread a lot also in technological position
- in this experiment knowledge influenced more than comparative advantages; it was waited, but not for technological position

Scenario D - Experiment 4

Description and waited result:

- I wait low movement from all nations. Low effect of knowledge should compensate the effect of comparative advantages
- in this experiment comparison in comparative advantages should not make the difference in technological position

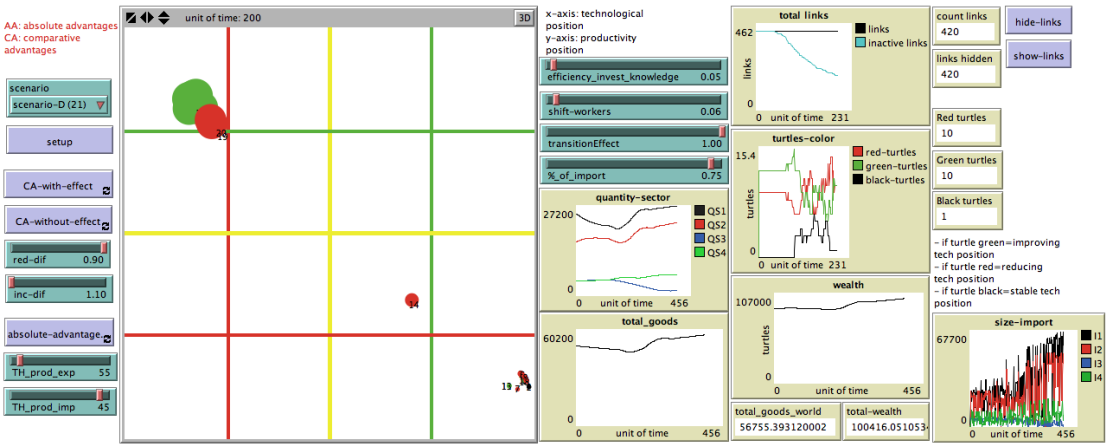


Figure 7.22: Experiment CA with effects - D4: result after 200 units of time

Results after 200 units of time (ticks):

- results are similar to experiment 2
- nations are divided in two groups: group on the left with high level of productivity but low level of workers in more technological sectors; group on the right with superiority of workers in high technological sectors but with low productivity
- this is owed to a low impact of knowledge, which does not allow to nations in improving productivity
- these observations are confirmed by quantity-sectors plot: production in sectors 1 and 2 is much higher than sectors 3 and 4
- analyzing nations' knowledge of the left group, it comes up it is negative for all of them: it means that knowledge had effect above all on technological position and not on productivity position

Scenario E - Experiment 1

Description and waited result:

- I wait much movement, both for technological and productivity position
- above all knowledge should influence a small break in the world between nations with positive and negative knowledge

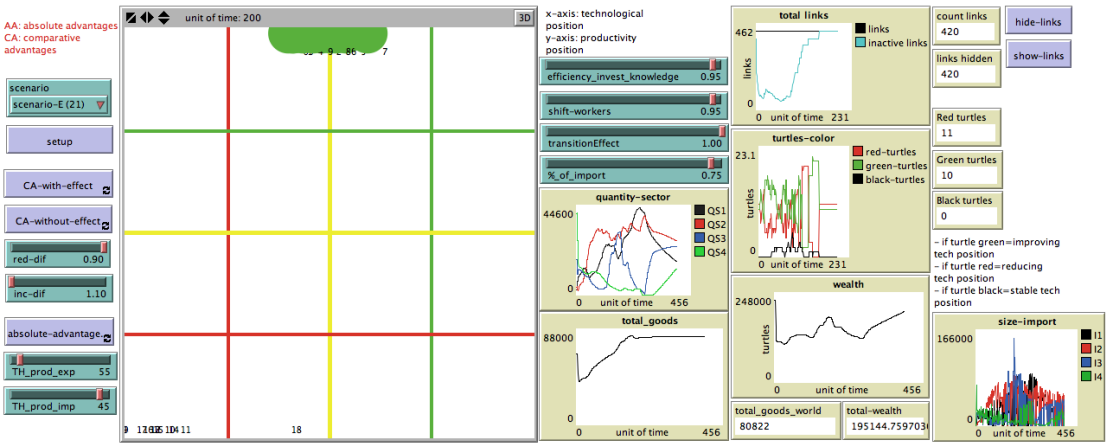


Figure 7.23: Experiment CA with effects - E1: result after 200 units of time

Results after 200 units of time (ticks):

- results are more extreme than waited
- nations with starting positive knowledge has increased in productivity position, while comparative advantages have a negative effect on technological position; nations with positive knowledge are the group in the middle high side
- the opposite for nations with negative knowledge: they are all on the left low side. Their productivity is too low to make some exchange possible

Scenario E - Experiment 2

Description and waited result:

- I wait that comparative advantages play a role, supporting nations with starting negative knowledge not to fall on the left down side
- nations with starting positive knowledge can be penalized

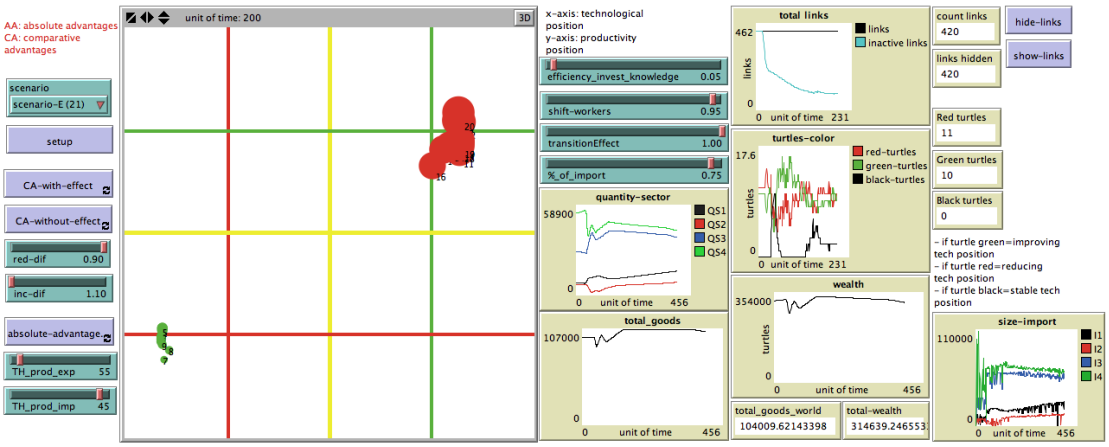


Figure 7.24: Experiment CA with effects - E2: result after 200 units of time

Results after 200 units of time (ticks):

- results are the classical example of what HH sustains: in a world where comparative advantages have a predominant role, nations with comparative advantages produce in sectors with high level of technology even if their knowledge is negative; this is true in the medium run
- in the long run, nations tend to suffer the effect of knowledge: all nations with positive knowledge (on the left side) tend to increase technological position, while it is the opposite for the nations on the right side
- naturally in this case the effect is very low

Scenario E - Experiment 3

Description and waited result:

- knowledge is the driver: I wait hugh movement both in technological and in productivity position
- comparative advantages should have a low effect; this is bad for nations with negative knowledge

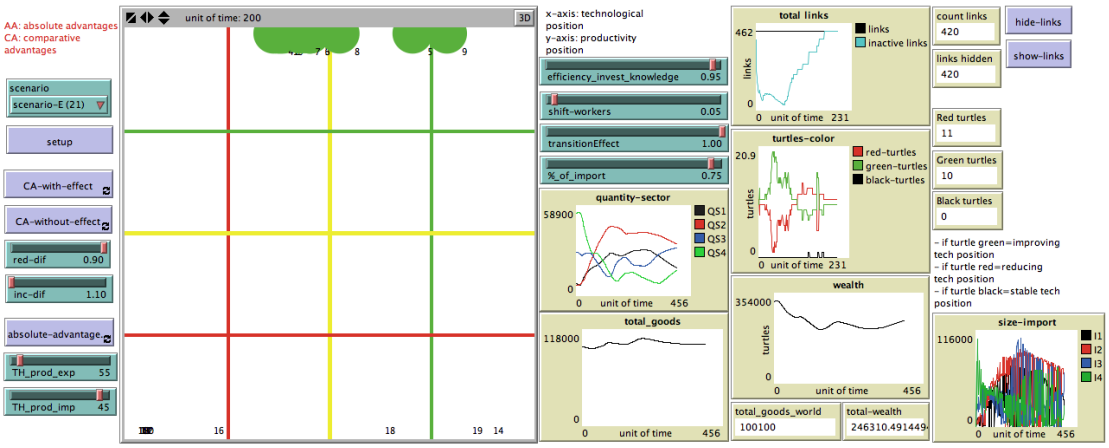


Figure 7.25: Experiment CA with effects - E3: result after 200 units of time

Results after 200 units of time (ticks):

- results are similar to experiment 1, more extreme than waited
- nations with starting positive knowledge increase in productivity position and keep a good technological position

Scenario E - Experiment 4

Description and waited result:

- I wait that comparative advantages play a role, supporting nations with starting negative knowledge not to fall on the left down side
- nations with starting positive knowledge can be penalized, as in experiment 2

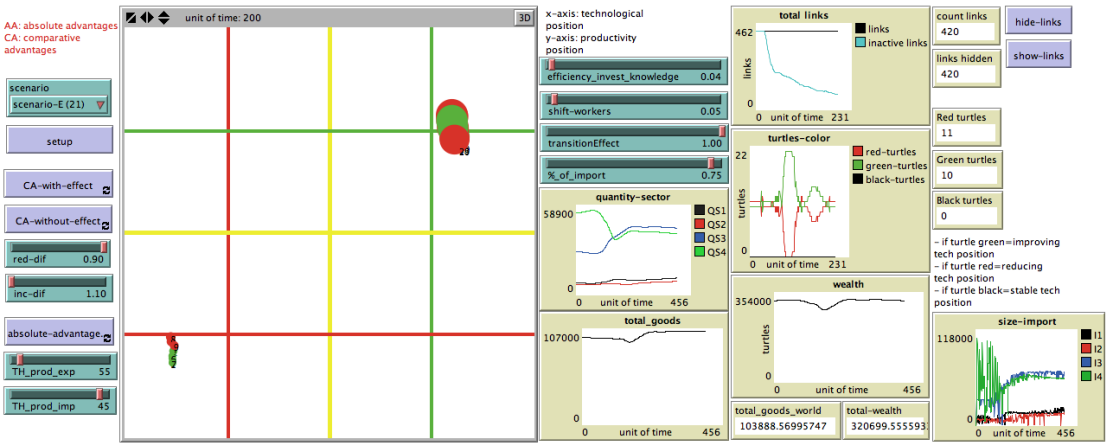


Figure 7.26: Experiment CA with effects - E4: result after 200 units of time

Results after 200 units of time (ticks):

- results are similar to experiment 2: in a world where comparative advantages have a predominant role, nations with comparative advantages produce in sectors with high level of technology even if their knowledge is negative; this is true in the medium run
- in the long run, nations tend to suffer the effect of knowledge, but in this experiment there is only a majority of nations with positive knowledge (on the left side), which tend to increase technological position, while it is the opposite for the nations on the right side

Scenario F - Experiment 1

Description and waited result:

- I wait that nations with positive knowledge, even if starting from left side (lower productivity position), tend to go up and right, improving also technological position
- nations with starting negative knowledge can be penalized, even if starting with an higher productivity position

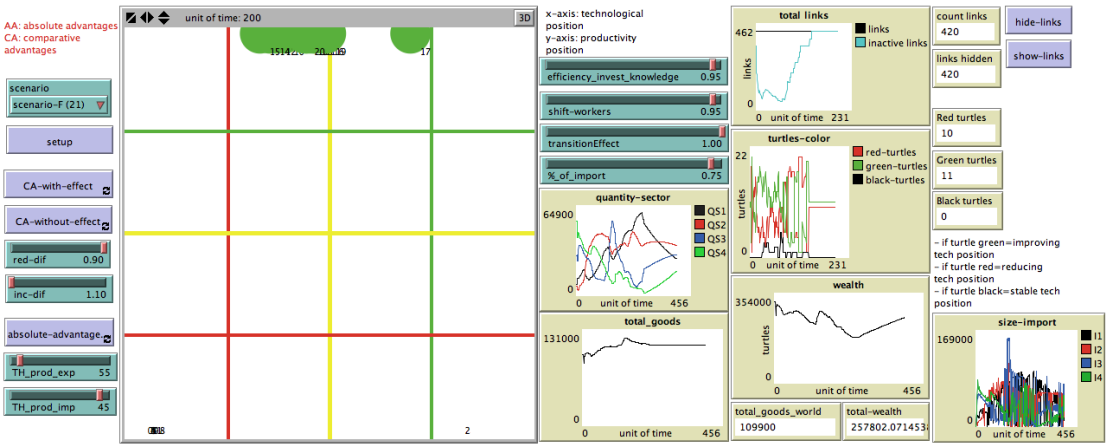


Figure 7.27: Experiment CA with effects - F1: result after 200 units of time

Results after 200 units of time (ticks):

- waited results are confirmed: nations with positive knowledge increase productivity position, while nations with negative knowledge decrease productivity position
- technological position decreases more for nations with negative knowledge respect to the increase for nations with positive knowledge

Scenario F - Experiment 2

Description and waited result:

- I wait that nations with starting positive knowledge does not improve their technological position
- nations with starting negative knowledge can be facilitated from higher shift of workers respect to effect of knowledge, increasing their technological position owed to comparative advantages

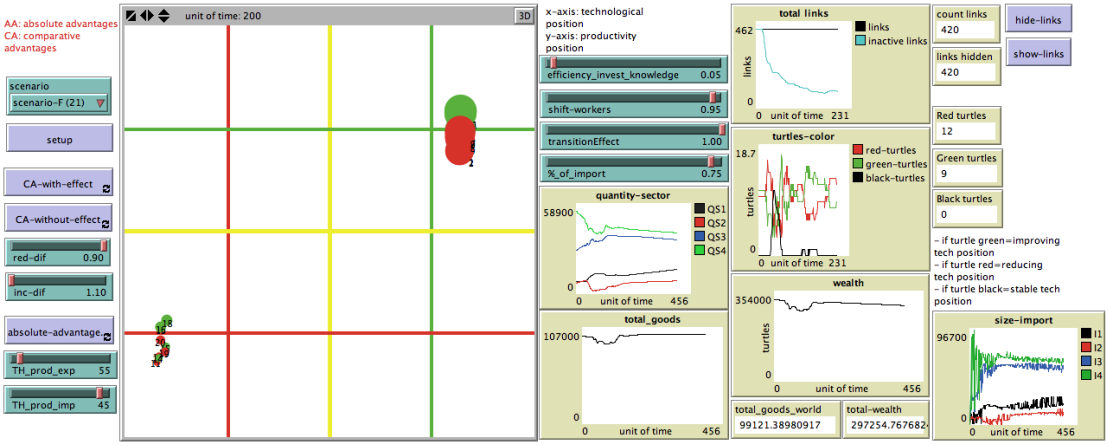


Figure 7.28: Experiment CA with effects - F2: result after 200 units of time

Results after 200 units of time (ticks):

- waited results are confirmed: nations with positive knowledge increase productivity position, while nations with negative knowledge decrease productivity position
- technological position decreases more for nations with negative knowledge respect to the increase for nations with positive knowledge

Scenario F - Experiment 3

Description and waited result:

- I wait that nations with starting positive knowledge, even starting from "poorer side", improve a lot both their technological position and productivity position, moving to high right side
- nations with starting negative knowledge should go down left, with both low technological position and productivity position

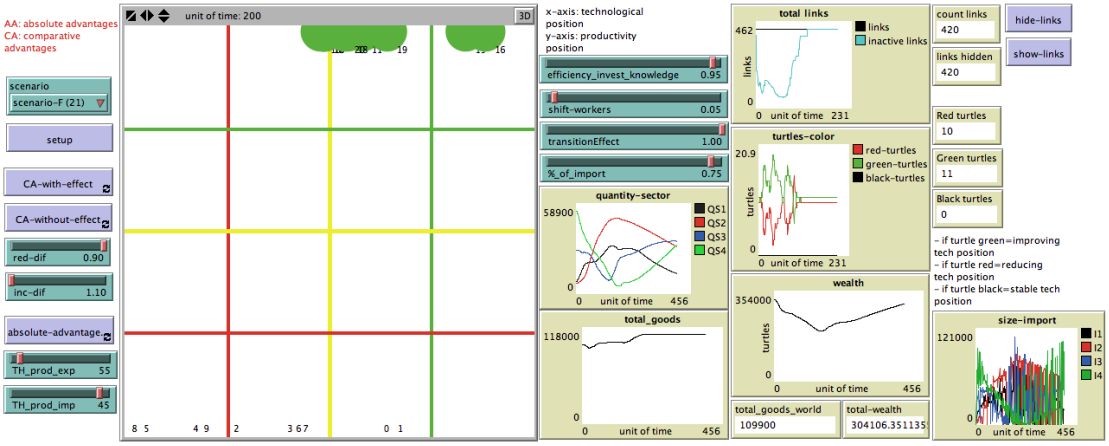


Figure 7.29: Experiment CA with effects - F3: result after 200 units of time

Results after 200 units of time (ticks):

- waited results are confirmed: during the first units of time nations with positive knowledge are pushed to the left down side because of the effect of comparative advantages, but then they recover their natural growth position
- the opposite for nations with starting negative knowledge: they seem to have an initial advantage, but then are condemned to a bad position

Scenario F - Experiment 4

Description and waited result:

- I wait that nations with starting positive knowledge are pushed down by the effect of comparative advantages, but with less effect than experiment 2
- nations with starting negative knowledge should improve position, because the effect of knowledge is lower than the shift of workers and comparative advantages

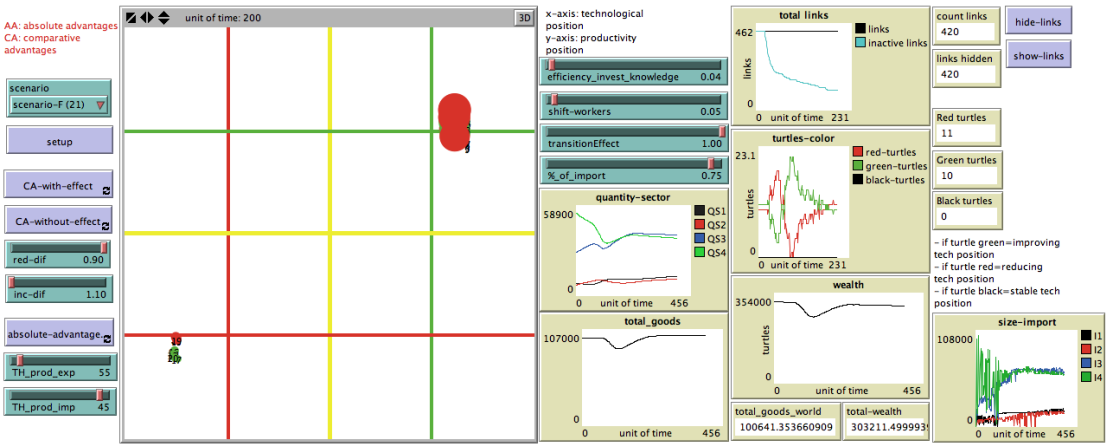


Figure 7.30: Experiment CA with effects - F4: result after 200 units of time

Results after 200 units of time (ticks):

- results are more similar to experiment 2 than waited, but green nations (and so growing nations) are more than previous experiment
- knowledge does not compensate the effect of comparative advantages and their shift of workers

7.3 Description of experiments: CA without effects on workers' quota

For high efficiency of investment in knowledge, it means this parameter is 0.95. If it is low, the parameter is 0.05.

Experiment 1

1) Efficiency of investment in knowledge: high

Experiment 2

1) Efficiency of investment in knowledge: low

7.3.1 Experiments on CA without effect on workers' quota

Scenario A - Experiment 1

Description and waited result:

- efficiency of investment in knowledge is high: I expect that countries with positive knowledge will move to the high right corner, meaning that inside them workers move to sectors with higher technology

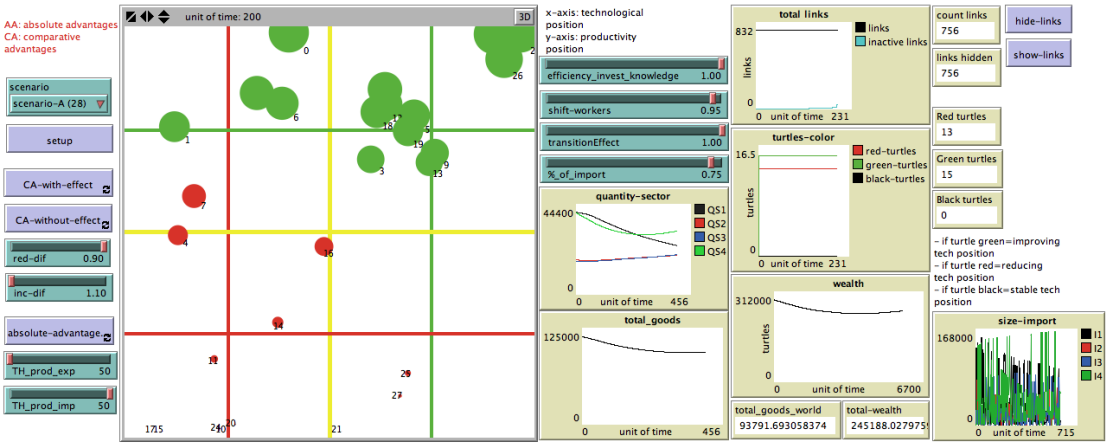


Figure 7.31: Experiment CA without effects - A1: result after 200 units of time

Results after 200 units of time (ticks):

- some nations moved to the down side, because their negative knowledge, while many nations improved both in productivity position and technoligical position

- there are many links active, meaning that if comparative advantages had effect, the final scenario would have been different

Scenario A - Experiment 2

Description and waited result:

- efficiency of investment in knowledge is low: I expect that countries tend to stay in the original position, even if with some little improvement for nations with positive knowledge

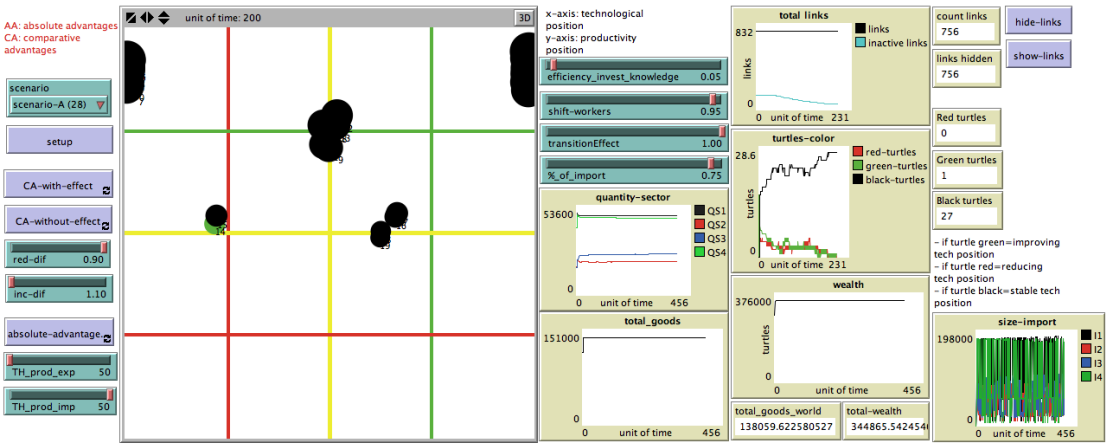


Figure 7.32: Experiment CA without effects - A2: result after 200 units of time

Results after 200 units of time (ticks):

- waited result is confirmed: nations tend to stay stable in the initial position, and almost all nations does not have any more strength to improve in technological position

Scenario B - Experiment 1

Description and waited result:

- even if nations start all from a low level in productivity, I wait an hugh difference between nations with positive knowledge and nations with negative knowledge, both in productivity and technological position

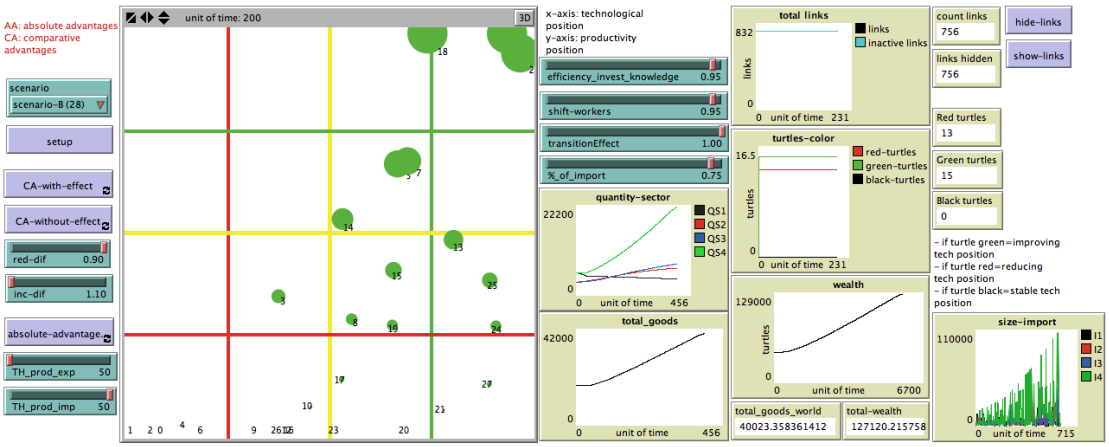


Figure 7.33: Experiment CA without effects - B1: result after 200 units of time

Results after 200 units of time (ticks):

- results are less extreme than expected, but knowledge makes the difference
- quantity produced in most technological sector increases, meaning that nations improve in this sector both number of workers and productivity, while quantity produced in the other sectors remains stable

Scenario B - Experiment 2

Description and waited result:

- I wait that some nations grow, but effect should be smoothed and i do not wait that nations reach the higher (more productive) side of the interface

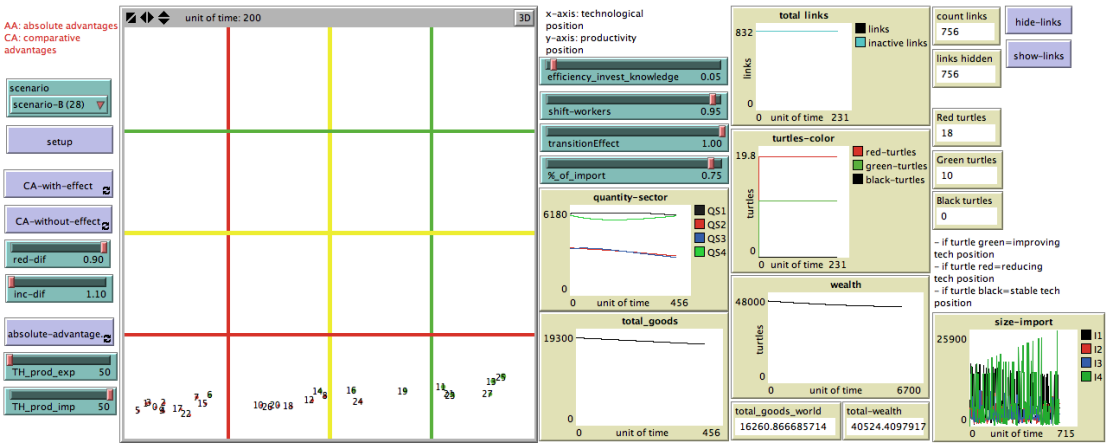


Figure 7.34: Experiment CA without effects - B2: result after 200 units of time

Results after 200 units of time (ticks):

- no nations is able to increase productivity.
- nations move only on the technological plan
- since there is low movement in productivity, nations are not able to create links among them

Scenario C - Experiment 1

Description and waited result:

- nations start with hugh differences in productivity and technological position, I wait that nations with positive knowledge would improve in both position
- nevertheless, i do not wait that nations with positive knowledge starting from left down side can reach the other nations, except if they have a great positive knowledge

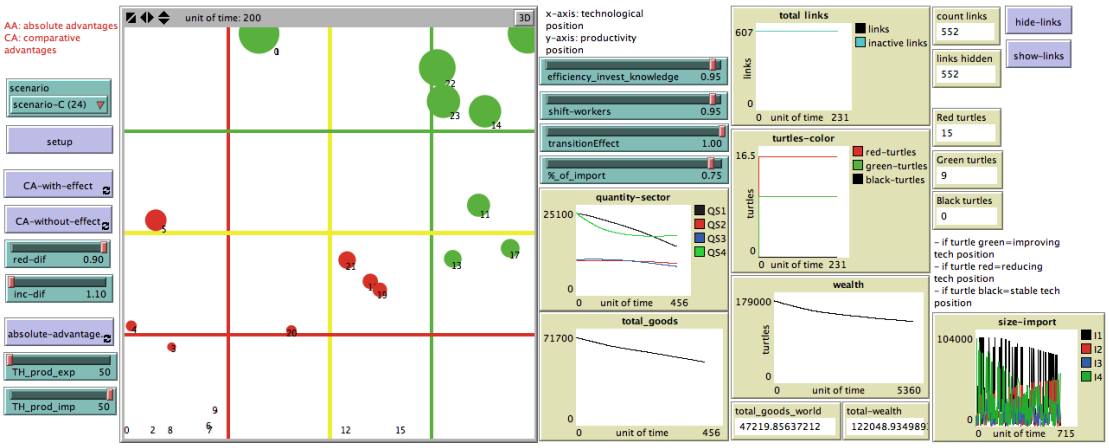


Figure 7.35: Experiment CA without effects - C1: result after 200 units of time

Results after 200 units of time (ticks):

- results satisfies the prevision, but some nations improve more the productivity and some nations improve more technological sector
- this is owed to the level of knowledge and initial productivity: nations 0 and 1 improve more productivity position than technological
- nations 11 and 13 was starting from the left down side, but they improve more in technological position than in productivity

Scenario C - Experiment 2

Description and waited result:

- nations start with hugh differences in productivity and technological position, but knowledge has now a low impact
- I wait basically the same results than previous experiment, but the effect is lower

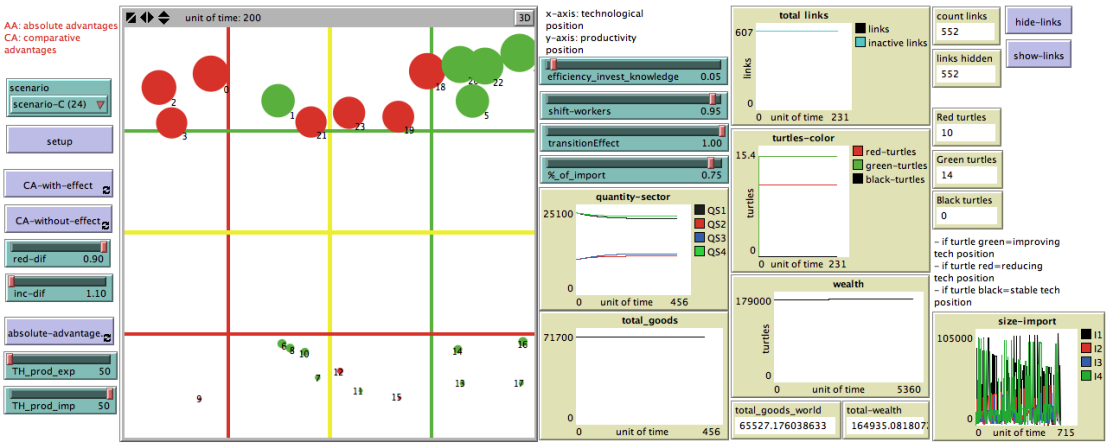


Figure 7.36: Experiment CA without effects - C2: result after 200 units of time

Results after 200 units of time (ticks):

- nations move only on the x-axis (technological position), while the movement on y-axis is negligible
- knowledge is too low, it has no power to increase or decrease productivity

Scenario D - Experiment 1

Description and waited result:

- I wait that nations with positive knowledge increase technological and productivity position
- I wait hugh difference among nations, owed to knowledge

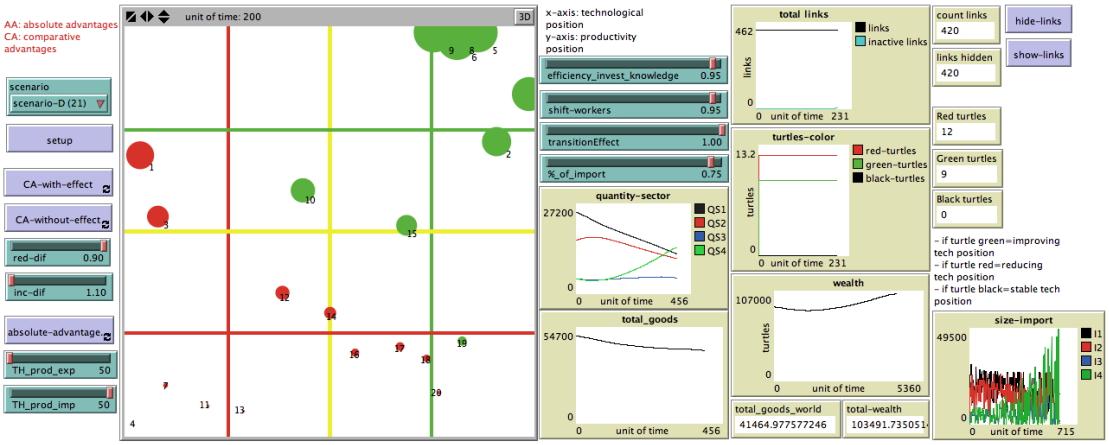


Figure 7.37: Experiment CA without effects - D1: result after 200 units of time

Results after 200 units of time (ticks):

- nations spread around the interface, with different behaviors, creating two groups
- nations with high volatility about level of knowledge tend to move away from starting point
- nations with low volatility about level if knowledge tend to stay stable around the starting point

Scenario D - Experiment 2

Description and waited result:

- I wait that nations move above all on the x-axis, based on knowledge, taking to stable productivity position but with some differences respect to technological position

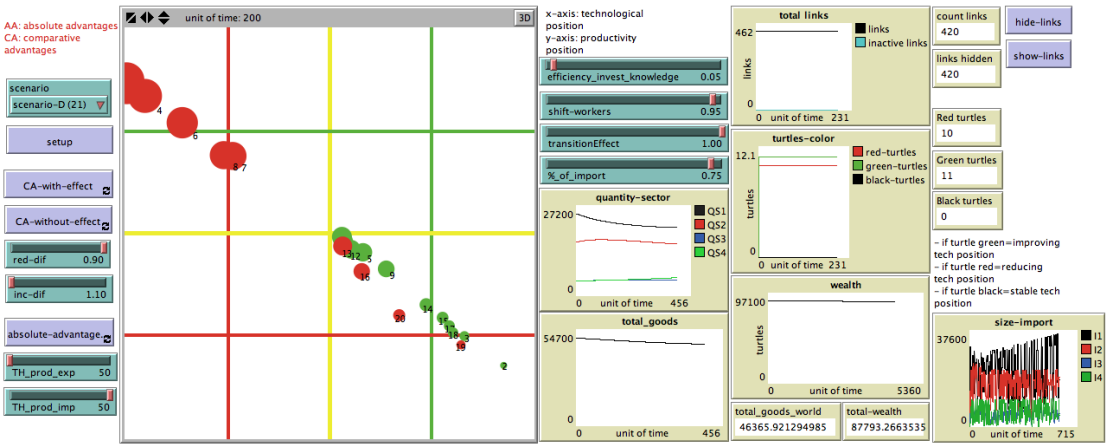


Figure 7.38: Experiment CA without effects - D2: result after 200 units of time

Results after 200 units of time (ticks):

- some nations increase or decrease technological position
- as waited, productivity tends to stay stable. Now knowledge influence more the technological aspect than productivity

Scenario E - Experiment 1

Description and waited result:

- I wait a hugh break among nations
- knowledge should have a great influence on both technological and productivity position, creating a break between nations with positive and with negative knowledge

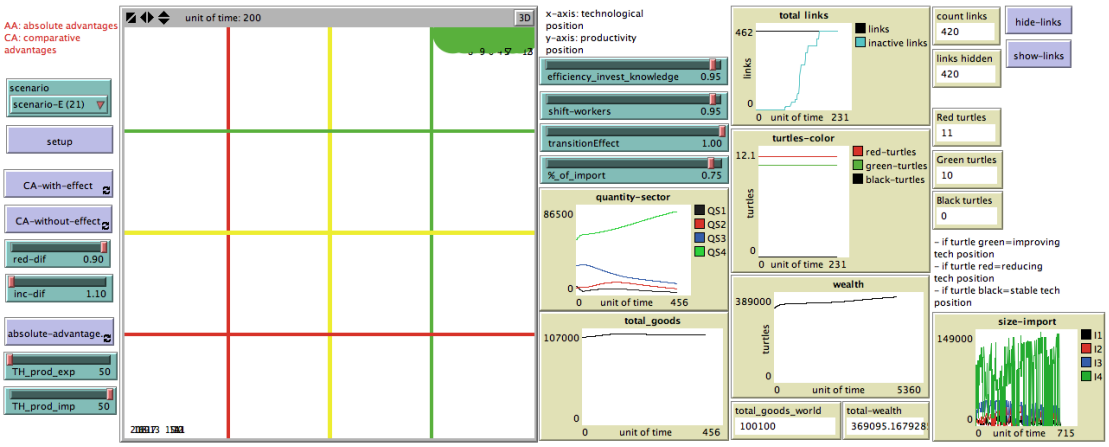


Figure 7.39: Experiment CA without effects - E1: result after 200 units of time

Results after 200 units of time (ticks):

- results satisfy expectation: nations divide literally in two blocks
- nations with positive knowledge reach the best position in term of productivity and technology
- nations with negative knowledge are in the worst position, with no hope to grow. The starting negative knowledge was a incontrovertible sentence

Scenario E - Experiment 2

Description and waited result:

- I wait basically the same results of the previous experiment, but with a lower effect
- nevertheless for nations with negative knowledge there is no way to improve their position

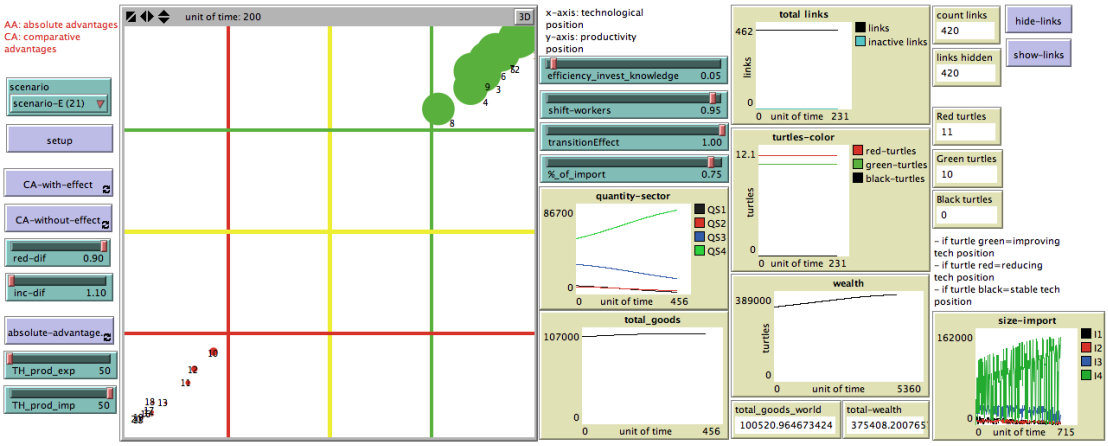


Figure 7.40: Experiment CA without effects - E2: result after 200 units of time

Results after 200 units of time (ticks):

- results satisfy expectation: nations divide literally in two blocks
- nations with positive knowledge reach the best position in term of productivity and technology, while nations with negative knowledge are in the worst position, with no hope to grow
- the difference is that nations tend to move on a balanced (technological and productive) way to the corners, while in the previous experiment they were pushed up or down by productivity

Scenario F - Experiment 1

Description and waited result:

- even if nations with positive knowledge start from a worst position, since effect of knowledge is high, I wait they move quickly to better position
- on the opposite side, nations with negative knowledge should move quickly to a worst position, with a hugh break among nations

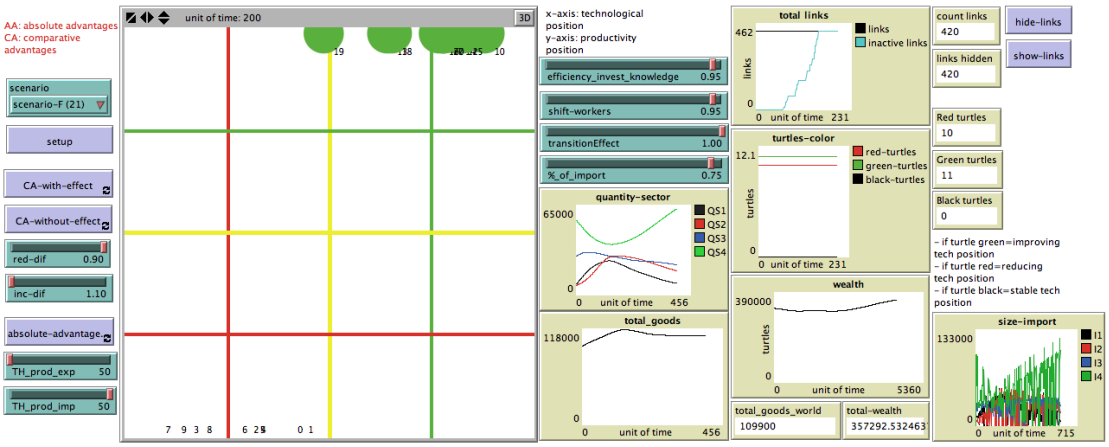


Figure 7.41: Experiment CA without effects - F1: result after 200 units of time

Results after 200 units of time (ticks):

- results satisfy expectation: nations divide literally in two blocks
- nations increase or decrease their productivity quicker than technology, but the movement is very relevant in both positions

Scenario F - Experiment 2

Description and waited result:

- I wait basically the same results of the previous experiment, but with less movement on productivity position and more on technological position

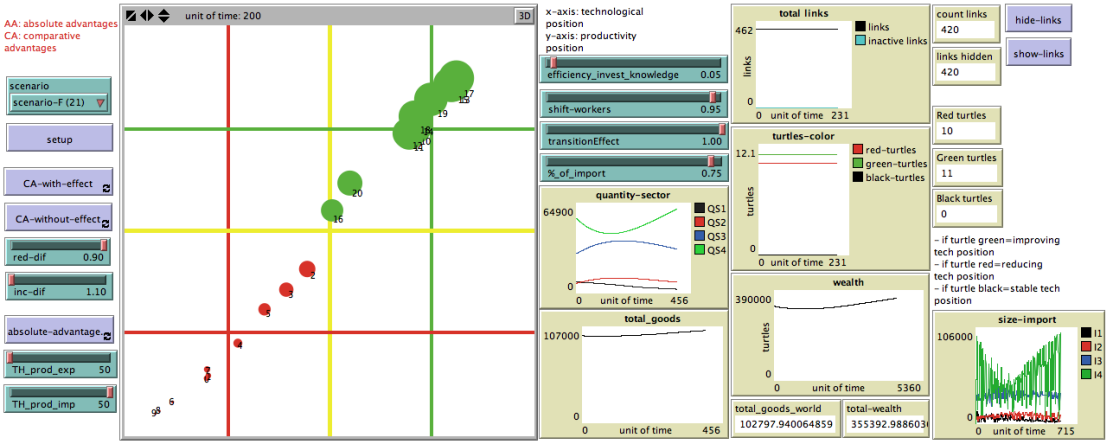


Figure 7.42: Experiment CA without effects - F2: result after 200 units of time

Results after 200 units of time (ticks):

- nations tend to move on balanced respect to productivity and technological position
- even if the movement is slower, the walk of nations is clear and in compliance with waited result

Chapter 8

General conclusions

This section is about opinions, and opinions are naturally debatable, even if associated with strong motivations. At first sight the theory of comparative advantages and the theory of economic complexity superimpose each other. But they have different goals. Let assume they can coexist. If we pay attention to the goal of these two theory, we come to the following conclusion: the theory of comparative advantages yearns for explaining what a nation should do with respect to another single nation. Alternatively, the theory of economic complexity, focusing on what single nations should do, yearns for explaining local and global growth, with respect to many other nations. But i need to stress that the main problem of theory of comparative advantages is the *one-to-one* foundation. Taking the discussion to the one-to-one comparison between two economic subjects (persons, firms or nations), this theory has an incredibly rational and economical relevance. A subject should specialize producing the good or service in which it is better, having lower opportunity costs in producing that particular good or service. It is persuasive. Nevertheless in the real World subjects are always more than two and economic dynamics become more complex. The theory of comparative advantages has a meaning if used to explain one-to-one dynamics, it has still meaning in small groups dynamics, but lose meaning if the subjects become many. The second problem of this theory is the following: it is valid if the behavior of subjects is cooperative. Two subjects compare their skills and decide which is the best trade-off to reach a better welfare for both. Again, in the real World nations cooperate but they tend to be selfish, more than persons usually do. Instead economic complexity theory focuses on nations' own behavior. These are reasons why theory of comparative advantages should be abandoned in favor of theories which aim to explain more complex dynamics, such as theory of economic complexity. Naturally I do not intend this work as a definitive sentences. Theories emerge and collapse. I tried to give my little contribute to describe a modern theory, comparing it with centerpieces of classical economic thought: this economic field necessitates further and deeper extensions. Further extensions may be investigations on the effect of demand for importations and exportations, or to analyze if international trade has effect on knowledge on productivity and economic growth of nations. Another extension would be analyzing changes in specific markets with introduction of new technologies, and how this brings to new economic sectors.

In the seven chapter of my thesis we saw many aspects of theories about international commerce. In the chapter 1 I gave a description about economic complexity theory, with some paradigmatic examples of its foundations. We looked to the World like it appears, providing a splinter of the real reasons that drive economic growth. In chapter 2 I introduced export with a brief historiography on how international trade were always active since we have sources. Then I

introduced more relevant theories about export, from Mercantilists during the end of Middle age going through cornerstones like Smith and Ricardo, coming to Modern age with Heckscher-Ohlin and Rybczynski. After I gave a taste of indexes and international classification of products. Since theories about export make an important use of productivity, I described theories about productivity in chapter 3. Starting from Solow-Swan theory which is a milestone if we speak about productivity and technology, I went to description of endogenous theory and AK model. Talking about technology I described the categorization of technical progress and how it is tied to human capital. Regarding to human capital, I introduced the most relevant model about its accumulation and efforts to calculate it. Beyond this part, I went to the third fundamental and most important word in this work, talking about knowledge in chapter 4. I tried to describe the real meaning of what we should intend with this word, once we purify it from common misleadings. Moreover, I recalled that knowledge it not just "something" we should increase, but also a part of our future if we preserve from the attempt to monetize it. Then I introduced more specific part of HH' theory of economic complexity foundations, providing a technical background and a critic to this theory. In chapter 5 we read a comparison of helpful tools in policy analysis, with a brief classification and description. After this part, I introduced some motivations about my decision to use NetLogo as tool to model the theories expressed in the previous chapters. Further I introduced my model in chapter 6, describing the different levels necessary to reach a good knowledge of programming language, providing an hint of interior mechanisms. Moreover, I tried to convey how i modeled the theories described in the first chapters. The next and conclusive chapter 7 described different scenarios and experiments I was able to make with my definitive model, with the aim to test numerically comparative advantages and economic complexity theories.

Appendices

.1 Bastiat's letter to French Parliament

Open letter to the French Parliament, originally published in 1845

A petition from the manufacturers of candles, tapers, lanterns, sticks, street lamps, snuffers, and extinguishers, and from producers of tallow, oil, resin, alcohol, and generally of everything connected with lighting.

To the Honourable Members of the Chamber of Deputies.

Gentlemen: You are on the right track. You reject abstract theories and have little regard for abundance and low prices. You concern yourselves mainly with the fate of the producer. You wish to free him from foreign competition, that is, to reserve the domestic market for domestic industry. We come to offer you a wonderful opportunity for your - what shall we call it? Your theory? No, nothing is more deceptive than theory. Your doctrine? Your system? Your principle? But you dislike doctrines, you have a horror of systems, as for principles, you deny that there are any in political economy; therefore we shall call it your practice - your practice without theory and without principle. We are suffering from the ruinous competition of a rival who apparently works under conditions so far superior to our own for the production of light that he is flooding the domestic market with it at an incredibly low price; for the moment he appears, our sales cease, all the consumers turn to him, and a branch of French industry whose ramifications are innumerable is all at once reduced to complete stagnation. This rival, which is none other than the sun, is waging war on us so mercilessly we suspect he is being stirred up against us by perfidious Albion (excellent diplomacy nowadays!), particularly because he has for that haughty island a respect that he does not show for us. We ask you to be so good as to pass a law requiring the closing of all windows, dormers, skylights, inside and outside shutters, curtains, casements, bull's-eyes, deadlights, and blinds - in short, all openings, holes, chinks, and fissures through which the light of the sun is wont to enter houses, to the detriment of the fair industries with which, we are proud to say, we have endowed the country, a country that cannot, without betraying ingratitude, abandon us today to so unequal a combat. Be good enough, honourable deputies, to take our request seriously, and do not reject it without at least hearing the reasons that we have to advance in its support. First, if you shut off as much as possible all access to natural light, and thereby create a need for artificial light, what industry in France will not ultimately be encouraged? If France consumes more tallow, there will have to be more cattle and sheep, and, consequently, we shall see an increase in cleared fields, meat, wool, leather, and especially manure, the basis of all agricultural wealth. If France consumes more oil, we shall see an expansion in the cultivation of the poppy, the olive, and rapeseed. These rich yet soil-exhausting plants will come at just the right time to enable us to put to profitable use the increased fertility that the breeding of cattle will impart to the land. Our moors will be covered with resinous trees. Numerous swarms of bees will gather from our mountains the perfumed treasures that today waste their fragrance, like the flowers from which they emanate. Thus, there is not one branch of agriculture that would not undergo a great expansion. The same holds true of shipping. Thousands of vessels will engage in whaling, and in a short time we shall have a fleet capable of upholding the honour of France and of gratifying the patriotic aspirations of the undersigned petitioners, chandlers, etc. But what shall we say of the specialities of Parisian manufacture? Henceforth you will behold gilding, bronze, and crystal in candlesticks, in lamps, in chandeliers, in candelabra sparkling in spacious emporia compared with which those of today are but stalls. There is no needy resin-collector on the heights of his sand dunes, no poor miner in the depths of his black pit, who will not receive higher wages and enjoy increased prosperity. It needs but a little reflection, gentlemen, to be convinced that there is perhaps not one Frenchman, from the wealthy stockholder of the Anzin Company to the humblest vendor of matches, whose condition would not be improved by the success of our petition. We anticipate your objections,

gentlemen; but there is not a single one of them that you have not picked up from the musty old books of the advocates of free trade. We defy you to utter a word against us that will not instantly rebound against yourselves and the principle behind all your policy. Will you tell us that, though we may gain by this protection, France will not gain at all, because the consumer will bear the expense?

We have our answer ready: You no longer have the right to invoke the interests of the consumer. You have sacrificed him whenever you have found his interests opposed to those of the producer. You have done so in order to encourage industry and to increase employment. For the same reason you ought to do so this time too. Indeed, you yourselves have anticipated this objection. When told that the consumer has a stake in the free entry of iron, coal, sesame, wheat, and textiles, "Yes," you reply, "but the producer has a stake in their exclusion." Very well, surely if consumers have a stake in the admission of natural light, producers have a stake in its interdiction.

"But," you may still say, "the producer and the consumer are one and the same person. If the manufacturer profits by protection, he will make the farmer prosperous. Contrariwise, if agriculture is prosperous, it will open markets for manufactured goods." Very well, If you grant us a monopoly over the production of lighting during the day, first of all we shall buy large amounts of tallow, charcoal, oil, resin, wax, alcohol, silver, iron, bronze, and crystal, to supply our industry; and, moreover, we and our numerous suppliers, having become rich, will consume a great deal and spread prosperity into all areas of domestic industry. Will you say that the light of the sun is a gratuitous gift of Nature, and that to reject such gifts would be to reject wealth itself under the pretext of encouraging the means of acquiring it? But if you take this position, you strike a mortal blow at your own policy; remember that up to now you have always excluded foreign goods because and in proportion as they approximate gratuitous gifts. You have only half as good a reason for complying with the demands of other monopolists as you have for granting our petition, which is in complete accord with your established policy; and to reject our demands precisely because they are better founded than anyone else's would be tantamount to accepting the equation: + x + = -; in other words, it would be to heap absurdity upon absurdity. Labour and Nature collaborate in varying proportions, depending upon the country and the climate, in the production of a commodity. The part that Nature contributes is always free of charge; it is the part contributed by human labour that constitutes value and is paid for. If an orange from Lisbon sells for half the price of an orange from Paris, it is because the natural heat of the sun, which is, of course, free of charge, does for the former what the latter owes to artificial heating, which necessarily has to be paid for in the market. Thus, when an orange reaches us from Portugal, one can say that it is given to us half free of charge, or, in other words, at half price as compared with those from Paris. Now, it is precisely on the basis of its being semigratuitous (pardon the word) that you maintain it should be barred. You ask: "How can French labour withstand the competition of foreign labour when the former has to do all the work, whereas the latter has to do only half, the sun taking care of the rest?" But if the fact that a product is half free of charge leads you to exclude it from competition, how can its being totally free of charge induce you to admit it into competition? Either you are not consistent, or you should, after excluding what is half free of charge as harmful to our domestic industry, exclude what is totally gratuitous with all the more reason and with twice the zeal. To take another example: When a product - coal, iron, wheat, or textiles - comes to us from abroad, and when we can acquire it for less labour than if we produced it ourselves, the difference is a gratuitous gift that is conferred up on us. The size of this gift is proportionate to the extent of this difference. It is a quarter, a half, or three-quarters of the value of the product if the foreigner asks of us only three-quarters, one-half, or one-quarter as high a price. It is as complete as it can be when the donor, like the sun in providing us with light, asks nothing from us. The question, and we pose it formally, is

whether what you desire for France is the benefit of consumption free of charge or the alleged advantages of onerous production. Make your choice, but be logical; for as long as you ban, as you do, foreign coal, iron, wheat, and textiles, in proportion as their price approaches zero, how inconsistent it would be to admit the light of the sun, whose price is zero all day long!

.2 NetLogo model

Full final NetLogo code used for the experiments.

```
extensions  [matrix array]
globals     [export total-wealth total_goods_world import-sectors
            size-sector-0 size-sector-1 size-sector-2 size-sector-3
            size-import-0 size-import-1 size-import-2 size-import-3 ]
turtles-own [knowledge changes labour-quota workers-in-sectors technologicalPosition
            productivity productivityPosition oldXcor oldYcor tot
            effect_of_invest_in_knowledge total-workers quantity-sectors
            total_goods sector-wealth prices wealth ]
links-own   [import total-import  status01 status02 status03 status12 status13 status23 ]



to setup

 ca
 ask patches [set pcolor 9.9]

 ask patches with [pxcor = 25]
 [set pcolor red]
 ask patches with [pxcor = 50]
 [set pcolor yellow]
 ask patches with [pxcor = 75]
 [set pcolor green]

 ask patches with [pycor = 25]
 [set pcolor red]
 ask patches with [pycor = 50]
 [set pcolor yellow]
 ask patches with [pycor = 75]
 [set pcolor green]



 if (scenario = "prova-1 (4)" )
 [file-open "setup-experiment-1.txt"
 crt file-read]

 if (scenario = "prova-2 (4)" )
 [file-open "setup-experiment-2.txt"
 crt file-read]

 if (scenario = "scenario-A (28)")
 [file-open "scenario-A.txt"
```

```
 crt file-read]

 if (scenario = "scenario-B (28)")
 [file-open "scenario-B.txt"
 crt file-read]

 if (scenario = "scenario-C (24)")
 [file-open "scenario-C.txt"
 crt file-read]

 if (scenario = "scenario-D (21)")
 [file-open "scenario-D.txt"
 crt file-read]

 if (scenario = "scenario-E (21)")
 [file-open "scenario-E.txt"
 crt file-read]

 if (scenario = "scenario-F (21)")
 [file-open "scenario-F.txt"
 crt file-read]



 ask turtles [set color grey
              set shape "circle"
              set label who
              set label-color black]

 setup-matrices




if (scenario = "prova-1 (4)"    )
 [file-open "setup-experiment-1.txt"

     while [not file-at-end?]
     [
       ask turtle file-read
        [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read

     matrix:set productivity 0 0 file-read
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read
     ] ]
```

```
   file-close]


if (scenario = "prova-2 (4)"    )
 [file-open "setup-experiment-2.txt"
     while [not file-at-end?]
     [
       ask turtle file-read
        [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read ] ]

   file-close ]


 if (scenario = "scenario-A (28)")
  [
file-open "scenario-A.txt"

     while [not file-at-end?]
     [
       ask turtle file-read
       [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read

     matrix:set productivity 0 0 file-read
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read
     ] ]

   file-close ]


 if (scenario = "scenario-B (28)")
 [file-open "scenario-B.txt"
   while [not file-at-end?]
 [ask turtle file-read
   [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read

     matrix:set productivity 0 0 file-read
```

```
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read]]
   file-close]


if (scenario = "scenario-C (24)")
 [file-open "scenario-C.txt"
   while [not file-at-end?]
 [ask turtle file-read
   [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read

     matrix:set productivity 0 0 file-read
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read]]
   file-close]



if (scenario = "scenario-D (21)")
 [file-open "scenario-D.txt"
   while [not file-at-end?]
 [ask turtle file-read
   [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read

     matrix:set productivity 0 0 file-read
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read]]
   file-close]



if (scenario = "scenario-E (21)")
 [file-open "scenario-E.txt"
   while [not file-at-end?]
 [ask turtle file-read
   [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read
```

```
     set total-workers file-read

     matrix:set productivity 0 0 file-read
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read]]
   file-close

   ask turtles
   [if who < 10
   [set knowledge knowledge + 1
   set color green]

  if who >= 10
 [set knowledge knowledge - 1
    set color red] ]]


if (scenario = "scenario-F (21)")
 [file-open "scenario-F.txt"
   while [not file-at-end?]
 [ask turtle file-read
   [matrix:set labour-quota 0 0 file-read
        matrix:set labour-quota 1 0 file-read
        matrix:set labour-quota 2 0 file-read
        matrix:set labour-quota 3 0 file-read

     set total-workers file-read

     matrix:set productivity 0 0 file-read
     matrix:set productivity 1 0 file-read
     matrix:set productivity 2 0 file-read
     matrix:set productivity 3 0 file-read]]
   file-close

   ask turtles
   [if who >= 10
   [set knowledge knowledge + 1
   set color green ]

  if who < 10
 [set knowledge knowledge - 1
    set color red] ]]



setup-technologicalPosition

setup-productivity

setup-size-of-nations
```

```
ask turtles [set total_goods_world sum [total_goods] of turtles  ]
plot-turtles

reset-ticks

tick

end


to setup-matrices

 ask turtles
 [
      set knowledge -0.5  + random-float 1

        set labour-quota        matrix:from-column-list [[0 0 0 0]]
        set changes             matrix:from-column-list [[0 0 0 0]]
        set productivity        matrix:from-column-list [[0 0 0 0]]
        set workers-in-sectors  matrix:from-column-list [[0 0 0 0]]
        set quantity-sectors    matrix:from-column-list [[0 0 0 0]]

        set sector-wealth      matrix:from-column-list [[0 0 0 0]]
        set prices              matrix:from-column-list [[1 2 3 4]]


        let sector 0
        while [sector < 4]
        [matrix:set productivity sector 0  1 + random-float 99
        set sector sector + 1] ]

end


to setup-technologicalPosition

 ask turtles
[ let sector 0
        while [sector < 4]
        [set tot (tot + matrix:get labour-quota sector 0 )
         set sector sector + 1]
; (0 + sec1) + (0 + sec2) + (0 + sec3) + (0 + sec4) = tot

      set sector 0
        set technologicalPosition 0

        while [sector < 4]
        [matrix:set labour-quota sector 0
         (matrix:get labour-quota sector 0 / tot)

         set technologicalPosition
         (technologicalPosition + (sector + 1) * matrix:get labour-quota sector 0)
```

```
         set sector sector + 1]
; TP = (0 + 1 * LQ1) +  (0 + 2 * LQ2) + (0 + 3 * LQ3) + (0 + 4 * LQ4)

        set xcor (technologicalPosition - 1 ) * 33]

end


to setup-productivity

ask turtles
[let sector 0
    set productivityPosition 0
      while [sector < 4]
     [set productivityPosition
          productivityPosition +
          (matrix:get productivity sector 0 * matrix:get labour-quota sector 0)
                set sector sector + 1]

     set ycor productivityPosition
]

end


to setup-size-of-nations

  ask turtles
  [let sector 0
  while [sector < 4]
  [matrix:set workers-in-sectors sector 0
   (matrix:get labour-quota sector 0 * total-workers)
    set sector sector + 1] ]

    ask turtles
[let sector 0
  while [sector < 4]
  [matrix:set quantity-sectors sector 0
    (matrix:get productivity sector 0 * matrix:get workers-in-sectors sector 0)
    set sector sector + 1] ]

ask turtles
 [let sector 0
 set total_goods 0
 while [sector < 4]
 [set total_goods (total_goods + matrix:get quantity-sectors sector 0)
    set sector sector + 1]

set sector 0
  while [sector < 4]
  [matrix:set sector-wealth sector 0
    (matrix:get quantity-sectors sector 0 * matrix:get prices sector 0)
    set sector sector + 1]
```

```
  set sector 0
 set wealth 0
 while [sector < 4]
 [set wealth wealth + matrix:get sector-wealth sector 0
    set sector sector + 1]


 set size ( total_goods / total-workers / 10 )  ]


ask turtles [set total_goods_world sum [total_goods] of turtles  ]
ask turtles [set total-wealth sum [wealth] of turtles  ]


size-sectors
plot-total_goods_world
quantity-sector
end


;----------------------



to technological-position

  ask turtles

 [if knowledge >= 0
     [let sector 0
      while [sector < 3] ;NB <3
       [matrix:set changes sector 0
        matrix:get labour-quota sector 0 * transitionEffect * knowledge
        set sector sector + 1]

        set sector 0
          while [sector < 3] ;NB <3
          [matrix:set workers-in-sectors (sector + 1) 0
          matrix:get workers-in-sectors (sector + 1) 0 +
          matrix:get changes sector 0
         matrix:set  workers-in-sectors  sector 0
         matrix:get workers-in-sectors  sector 0 -
         matrix:get changes sector 0

        set sector sector + 1]]

  if knowledge < 0
     [let sector 3

        while [sector > 0] ;NB >0
        [matrix:set changes sector 0
         matrix:get labour-quota sector 0 * transitionEffect * knowledge
```

```
         ;NB knowledge<0
        set sector sector - 1]

        set sector 3
         while [sector > 0] ;NB >0
          [matrix:set workers-in-sectors sector 0
          matrix:get workers-in-sectors  sector 0 +
          matrix:get changes sector 0
          matrix:set workers-in-sectors (sector - 1) 0
          matrix:get workers-in-sectors (sector - 1) 0 -
          matrix:get changes sector 0

        set sector sector - 1]]]


 ask turtles [
  let sector 0
  while [sector < 4]
  [matrix:set labour-quota sector 0
  (matrix:get workers-in-sectors sector 0 / total-workers)
    set sector sector + 1]]


  ask turtles
  [let sector 0
    set technologicalPosition 0
    while [sector < 4]
     [set technologicalPosition
       (technologicalPosition + (sector + 1) * matrix:get labour-quota sector 0)
      set sector sector + 1]

    set oldXcor xcor

    if technologicalPosition > 4 [set technologicalPosition 4]
    if technologicalPosition < 1 [set technologicalPosition 1]

   set xcor (technologicalPosition - 1) * 33

    if xcor > oldXcor [set color green]
    if xcor < oldXcor [set color red]
    if xcor = oldXcor [set color black] ]

end


to productivity-position

ask turtles
[set effect_of_invest_in_knowledge
   (knowledge * efficiency_invest_knowledge )]

   ask turtles
     [let sector 0
```

```
       while [sector < 4]
        [matrix:set productivity sector 0
          (matrix:get productivity sector 0 + effect_of_invest_in_knowledge)
        set sector sector + 1]

  if matrix:get productivity 0 0 < 1 [matrix:set productivity 0 0 1]
  if matrix:get productivity 1 0 < 1 [matrix:set productivity 1 0 1]
  if matrix:get productivity 2 0 < 1 [matrix:set productivity 2 0 1]
  if matrix:get productivity 3 0 < 1 [matrix:set productivity 3 0 1]
  if matrix:get productivity 0 0 > 99 [matrix:set productivity 0 0 99]
  if matrix:get productivity 1 0 > 99 [matrix:set productivity 1 0 99]
  if matrix:get productivity 2 0 > 99 [matrix:set productivity 2 0 99]
  if matrix:get productivity 3 0 > 99 [matrix:set productivity 3 0 99]


    set sector 0
    set productivityPosition 0
      while [sector < 4]

    [ set productivityPosition productivityposition +
      (matrix:get productivity sector 0 * matrix:get labour-quota sector 0)
      set sector sector + 1]

    set ycor productivityPosition ]

end

to size-of-nations

  ask turtles
 [let sector 0
  while [sector < 4]
  [matrix:set workers-in-sectors sector 0
    matrix:get labour-quota sector 0 * total-workers
    set sector sector + 1] ]


    ask turtles
[  let sector 0
  while [sector < 4]
  [matrix:set quantity-sectors sector 0
    (matrix:get workers-in-sectors sector 0 *
     matrix:get productivity sector 0)

    set sector sector + 1]

 set sector 0
 set total_goods 0
 while [sector < 4]
 [set total_goods
      total_goods + matrix:get quantity-sectors sector 0
    set sector sector + 1
    ]
```

```
 set sector 0
  while [sector < 4]
  [matrix:set sector-wealth sector 0
    (matrix:get quantity-sectors sector 0 * matrix:get prices sector 0)
    set sector sector + 1]

  set sector 0
 set wealth 0
 while [sector < 4]
 [set wealth wealth + matrix:get sector-wealth sector 0
    set sector sector + 1]

 set size (total_goods / total-workers / 10)]

ask turtles [set total_goods_world sum [total_goods] of turtles  ]
ask turtles [set total-wealth sum [wealth] of turtles  ]

size-sectors
plot-total_goods_world
quantity-sector

end


to size-sectors

   ask turtles [
     set size-sector-0 sum [matrix:get quantity-sectors 0 0]  of turtles]

   ask turtles [
     set size-sector-1 sum [matrix:get quantity-sectors 1 0] of turtles]

   ask turtles [
     set size-sector-2 sum [matrix:get quantity-sectors 2 0] of turtles]

   ask turtles [
     set size-sector-3 sum [matrix:get quantity-sectors 3 0] of turtles]
 end

to quantity-sector
  set-current-plot "quantity-sector"

  set-current-plot-pen "QS1"
  plot size-sector-0
  set-current-plot-pen "QS2"
  plot size-sector-1
  set-current-plot-pen "QS3"
  plot size-sector-2
  set-current-plot-pen "QS4"
  plot size-sector-3
end
```

```
to import-of-sectors
  ask turtles [
    set size-import-0 sum [matrix:get import-sectors 0 0] of turtles]
 ask turtles [
    set size-import-1 sum [matrix:get import-sectors 1 0] of turtles]
 ask turtles [
    set size-import-2 sum [matrix:get import-sectors 2 0] of turtles]
 ask turtles [
    set size-import-3 sum [matrix:get import-sectors 3 0] of turtles]

  set-current-plot "size-import"

  set-current-plot-pen  "I1"
  plot size-import-0
  set-current-plot-pen "I2"
  plot size-import-1
  set-current-plot-pen "I3"
  plot size-import-2
  set-current-plot-pen "I4"
  plot size-import-3
end
```

```
to links-import
ask links
[set import-sectors  matrix:from-column-list  [[0 0 0 0]] ]

  ask links
  [if
    [matrix:get quantity-sectors 0 0] of end1 < [matrix:get quantity-sectors 0 0] of end2
    [ask end1 [ask out-link-to other-end
    [matrix:set import-sectors 0 0 [matrix:get quantity-sectors 0 0] of end2 * %_of_import]
        ]]
   if
     [matrix:get quantity-sectors 1 0] of end1 < [matrix:get quantity-sectors 1 0] of end2
     [ask end1 [ask out-link-to other-end
     [matrix:set import-sectors 1 0 [matrix:get quantity-sectors 1 0] of end2 * %_of_import]
      ]]
   if
     [matrix:get quantity-sectors 2 0] of end1 < [matrix:get quantity-sectors 2 0] of end2
     [ask end1 [ask out-link-to other-end
     [matrix:set import-sectors 2 0 [matrix:get quantity-sectors 2 0] of end2 * %_of_import]
     ]]
   if
     [matrix:get quantity-sectors 3 0] of end1 < [matrix:get quantity-sectors 3 0] of end2
     [ask end1 [ask out-link-to other-end
     [matrix:set import-sectors 3 0 [matrix:get quantity-sectors 3 0] of end2 * %_of_import]
     ]]
      ]
```

```
  ask links
  [let sector 0
    while [sector < 4]
    [set total-import
     total-import + matrix:get import-sectors sector 0
     set sector sector + 1]]

  ask links [set thickness total-import / 10000]

  ask links [if total-import <= 0 [hide-link]]

end





to absolute-advantage_AA

  clear-links

  ask turtles
   [let sector 0
     if matrix:get productivity sector 0 < TH_prod_imp  ;threshold productivity importer
     [while [sector < 4]
     [create-links-to other turtles with
       [matrix:get productivity sector 0 > TH_prod_exp] ;threshold productivity exporter
       set sector sector + 1]]]


parameter
technological-position
parameter
productivity-position
parameter
size-of-nations

parameter

ask links
  [ifelse
    [size] of end1 > [size] of end2
  [ask end2
  [if out-link-to other-end != nobody [ask out-link-to other-end
      [set import ([size] of end2) * %_of_import]]]]
[
  if
    [size] of end2 > [size] of end1
    [ask end1
    [ask out-link-to other-end
    [set import ([size] of end1) * %_of_import ]]]]]
```

```
  ask links [if import = 0 [hide-link]]

  ask links [set thickness import]
  ask links [set color import * 2]


plot-turtles
plot-link

tick
if ticks >= 200 [stop]

end


to CA-with-effect

parameter

clear-links

 ask turtles [
   create-links-to other turtles ]

ask links [hide-link]

technological-position
parameter
productivity-position
parameter

p1Vp2-CA-with-effect
p1Vp3-CA-with-effect
p1Vp4-CA-with-effect
p2Vp3-CA-with-effect
p2Vp4-CA-with-effect
p3Vp4-CA-with-effect

parameter
size-of-nations
parameter

links-import

import-of-sectors
plot-link
plot-turtles
plot-wealth


  tick
```

```
if ticks >= 200 [stop]
 end


to CA-without-effect

  clear-links

  ask turtles [
   create-links-to other turtles]

  ask turtles [hide-links]


technological-position
parameter
productivity-position
parameter

p1Vp2-CA-without-effects
p1Vp3-CA-without-effects
p2Vp3-CA-without-effects
p1Vp4-CA-without-effects
p3Vp4-CA-without-effects
p2Vp4-CA-without-effects

parameter
size-of-nations
parameter

links-import
import-of-sectors
plot-link
ask turtles[plot-wealth]
plot-turtles
import-of-sectors



tick
if ticks >= 200 [stop]
end


to  p1Vp2-CA-with-effect


ask links[

 ifelse
     [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2) * inc-dif
   <
```

```
     [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2) * red-dif

  [ask end1

       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 + shift-workers]
  ask end2
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 + shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers]

 ask end1
 [ask out-link-to other-end [set status01 "1-0"
     ]
 ask in-link-from other-end [show-link]
   ]]

  [if [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2) * red-dif
    >
      [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2) * inc-dif

  [ask end1
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 + shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers]
  ask end2
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 + shift-workers]


  ask end1
    [ask out-link-to other-end [set status01 "0-1"
        ]
    ask in-link-from other-end [show-link]
      ]]
 ]  ]


end

to p1Vp3-CA-with-effect
ask links [
  ifelse
[matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2) * inc-dif
   <
[matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2) * red-dif
```

```
[ask end1
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 + shift-workers]

 ask end2
  [matrix:set workers-in-sectors 2 0
   matrix:get workers-in-sectors 2 0 - shift-workers
   matrix:set workers-in-sectors 0 0
   matrix:get workers-in-sectors 0 0 + shift-workers]

  ask end1
 [ask out-link-to other-end [set status02 "2-0"
     ]
 ask in-link-from other-end [show-link]
   ]]

   [ if
    [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2) * red-dif
   >
    [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2) * inc-dif



    [ask end1
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 + shift-workers
        matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 - shift-workers]
  ask end2
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 + shift-workers]
  ask end1
 [ask out-link-to other-end [set status02 "0-2"
     ]
 ask in-link-from other-end [show-link]
   ]]
   ]]

end

to p1Vp4-CA-with-effect
ask links [
  ifelse
     [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2) * inc-dif
   <
     [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2) * red-dif

[ask end1
       [matrix:set workers-in-sectors 0 0
```

```
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 + shift-workers]

 ask end2
  [matrix:set workers-in-sectors 3 0
   matrix:get workers-in-sectors 3 0 - shift-workers
   matrix:set workers-in-sectors 0 0
   matrix:get workers-in-sectors 0 0 + shift-workers]

  ask end1
 [ask out-link-to other-end [set status03 "3-0"
     ]
 ask in-link-from other-end [show-link]
  ]]

   [ if
    [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2) * red-dif
   >
    [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2) * inc-dif

    [ask end1
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 + shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 - shift-workers]
  ask end2
       [matrix:set workers-in-sectors 0 0
        matrix:get workers-in-sectors 0 0 - shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 + shift-workers]

  ask end1
 [ask out-link-to other-end [set status03 "0-3"
     ]
 ask in-link-from other-end [show-link]
 ]]
   ]
]

end

to p2Vp3-CA-with-effect
ask links [
  ifelse
     [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2) * inc-dif
   <
     [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2) * red-dif

  [ask end1
       [matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers
        matrix:set workers-in-sectors 2 0
```

```
        matrix:get workers-in-sectors 2 0 + shift-workers]

 ask end2
  [matrix:set workers-in-sectors 2 0
   matrix:get workers-in-sectors 2 0 - shift-workers
   matrix:set workers-in-sectors 1 0
   matrix:get workers-in-sectors 1 0 + shift-workers]

  ask end1
 [ask out-link-to other-end [set status12 "2-1"
     ]
 ask in-link-from other-end [show-link]
   ]]

   [ if
    [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2) * red-dif
   >
    [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2) * inc-dif

    [ask end1
       [matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 + shift-workers
        matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 - shift-workers]
  ask end2
       [matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers
        matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 + shift-workers]
  ask end1
 [ask out-link-to other-end [set status12 "1-2"
     ]
 ask in-link-from other-end [show-link]
 ]]
   ]]

end


to p2Vp4-CA-with-effect
ask links [
  ifelse
     [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2) * inc-dif
   <
     [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2) * red-dif

[ask end1
       [matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 + shift-workers]

 ask end2
```

```
  [matrix:set workers-in-sectors 3 0
   matrix:get workers-in-sectors 3 0 - shift-workers
   matrix:set workers-in-sectors 1 0
   matrix:get workers-in-sectors 1 0 + shift-workers]

  ask end1
 [ask out-link-to other-end [set status13 "3-1"
     ]
 ask in-link-from other-end [show-link]

     ]]

   [ if
    [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2) * red-dif
   >
    [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2) * inc-dif

    [ask end1
       [matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 + shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 - shift-workers]
    ask end2
       [matrix:set workers-in-sectors 1 0
        matrix:get workers-in-sectors 1 0 - shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 + shift-workers]

 ask end1
 [ask out-link-to other-end [set status13 "1-3"
     ]
 ask in-link-from other-end [show-link]
  ]]
   ]]


end


to p3Vp4-CA-with-effect
ask links [
  ifelse
     [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2) * inc-dif
   <
     [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2) * red-dif

 [ask end1
       [matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 - shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 + shift-workers]

 ask end2
```

```
  [matrix:set workers-in-sectors 3 0
   matrix:get workers-in-sectors 3 0 - shift-workers
   matrix:set workers-in-sectors 2 0
   matrix:get workers-in-sectors 2 0 + shift-workers]

  ask end1
 [ask out-link-to other-end [set status23 "3-2"
     ]
 ask in-link-from other-end [show-link]
 ]]

   [ if
    [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2) * red-dif
   >
    [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2) * inc-dif

         [ask end1
       [matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 + shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 - shift-workers]
  ask end2
       [matrix:set workers-in-sectors 2 0
        matrix:get workers-in-sectors 2 0 - shift-workers
        matrix:set workers-in-sectors 3 0
        matrix:get workers-in-sectors 3 0 + shift-workers]

   ask end1
 [ask out-link-to other-end [set status23 "2-3"
     ]
 ask in-link-from other-end [show-link]
 ]]
   ]]

end

 to p1Vp2-CA-without-effects

   ask links[
 ifelse
     [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2)
   <
     [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2)


  [ask end1
    [ ask out-link-to other-end [set status01 "1-0"]
      ask in-link-from other-end [show-link] ]]

   [if
  [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2)
    >
  [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2)
```

```
  [ask end1
   [ ask out-link-to other-end [set status01 "0-1"]
     ask in-link-from other-end [show-link] ]]
   ] ]

 end

to p1Vp3-CA-without-effects
ask links [
  ifelse
     [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2)
   <
     [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2)

  [ask end1
    [ask out-link-to other-end  [set status02 "2-0"]
      ask in-link-from other-end [show-link] ]]

 [if
    [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2)
   >
    [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2)


  [ask end1
    [ask out-link-to other-end  [set status02 "0-2"]
      ask in-link-from other-end [show-link] ]]
] ]

end

to p2Vp3-CA-without-effects
ask links [
  ifelse
     [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2)
   <
     [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2)
 [ask end1
  [ask out-link-to other-end [set status12 "2-1"]
    ask in-link-from other-end [show-link] ]]

 [if
    [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2)
   >
    [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2)


   [ask end1
     [ask out-link-to other-end [set status12 "1-2"]
       ask in-link-from other-end [show-link] ]]
```

```
] ]
end

to p1Vp4-CA-without-effects
ask links [
  ifelse
     [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2)
   <
     [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2)

  [ask end1
   [ask out-link-to other-end [set status03 "3-0"]
     ask in-link-from other-end [show-link] ]]


   [if
    [matrix:get productivity 0 0] of (end1) / [matrix:get productivity 0 0] of (end2)
   >
    [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2)

   [ask end1
    [ask out-link-to other-end [set status03 "0-3"]
      ask in-link-from other-end [show-link] ] ]]
     ]

end

to p3Vp4-CA-without-effects
ask links [
  ifelse
     [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2)
   <
     [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2)

[ask end1
  [ask out-link-to other-end [set status23 "3-2"]
    ask in-link-from other-end [show-link] ]  ]

[if
    [matrix:get productivity 2 0] of (end1) / [matrix:get productivity 2 0] of (end2)
   >
    [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2)

   [ask end1
     [ask out-link-to other-end [set status23 "2-3"]
       ask in-link-from other-end [show-link] ] ]]
]


end


to p2Vp4-CA-without-effects
```

```
ask links [
  ifelse
     [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2)
   <
     [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2)

[ask end1
  [ask out-link-to other-end [set status13 "3-1"]
    ask in-link-from other-end [show-link] ]]

[if
    [matrix:get productivity 1 0] of (end1) / [matrix:get productivity 1 0] of (end2)
   >
    [matrix:get productivity 3 0] of (end1) / [matrix:get productivity 3 0] of (end2)


   [ask end1
     [ask out-link-to other-end [set status13 "1-3"]
       ask in-link-from other-end [show-link]  ]]]
]


end




to plot-link

  set-current-plot "total links"
  set-current-plot-pen "links"
  plot count links

  set-current-plot-pen "inactive links"
  plot count links with [hidden? = true]
end

to hide-links
ask links
[set hidden? true]
end

to show-links
ask links
[set hidden? false]
end

to plot-turtles
  set-current-plot "turtles-color"
  set-current-plot-pen "red-turtles"
  plot count turtles with [color = red]
  set-current-plot-pen "green-turtles"
```

```
  plot count turtles with [color = green]
  set-current-plot-pen "black-turtles"
  plot count turtles with [color = black]
end

to plot-wealth
  set-current-plot "wealth"
  set-current-plot-pen "rich"
  plot total-wealth
end


to plot-total_goods_world
  set-current-plot "total_goods"
  set-current-plot-pen "goods"
  plot total_goods_world
end


 to PARAMETER

   ask turtles
 [if matrix:get workers-in-sectors 0 0 <= 0 [matrix:set workers-in-sectors 0 0 0]
  if matrix:get workers-in-sectors 1 0 <= 0 [matrix:set workers-in-sectors 1 0 0]
  if matrix:get workers-in-sectors 2 0 <= 0 [matrix:set workers-in-sectors 2 0 0]
  if matrix:get workers-in-sectors 3 0 <= 0 [matrix:set workers-in-sectors 3 0 0]]


ask turtles [
  let sector 0
  while [sector < 4]
  [matrix:set labour-quota sector 0 matrix:get workers-in-sectors sector 0 / total-workers
    set sector sector + 1]]


ask turtles [
let sector 0
set tot 0
while [sector < 4]
[set tot (tot + matrix:get labour-quota sector 0)
  set sector sector + 1]

set sector 0
while [sector < 4]
[matrix:set labour-quota sector 0 (matrix:get labour-quota sector 0 / tot)
  set sector sector + 1]]




ask turtles [
 let sector 0
 set labour-quota-tot 0
```

```
while [sector < 4]
[set labour-quota-tot labour-quota-tot + matrix:get labour-quota sector 0
   set sector sector + 1]]


END
```

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