Artificial intelligence between Big Science and Small Science: an Italian strategy to compete

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This article presents a strategic analysis on the situation and the possible developments of Artificial intelligence (AI) from a scientific but also an economic and business point of view. It contrasts the two complementary paths of Big Science and Small Science by analyzing two case studies: machine translation and the Economic Fitness and Complexity framework, a new methodology that provides superior insight into economic development with fewer but carefully chosen data. It then examine the implications of AI for the labor market and assess Italy's position, which can become a global leader in Small Science for AI by leveraging interdisciplinarity and complexity science, ingenuity, and talent attraction.

Questo articolo presenta un'analisi strategica della situazione e dei possibili sviluppi dell'Intelligenza artificiale (IA) da un punto di vista scientifico, ma anche economico e aziendale. Si confrontano i due percorsi complementari di Big Science e Small Science analizzando due casi di studio: la traduzione automatica e il framework Economic Fitness and Complexity, una nuova metodologia che fornisce una visione approfondita dello sviluppo economico con un numero inferiore di dati, ma accuratamente selezionati. Si esaminano quindi le implicazioni dell'IA per il mercato del lavoro e si valuta la posizione dell'Italia, che può orientarsi a diventare un leader globale nella Small Science per l'Intelligenza artificiale, sfruttando interdisciplinarità e scienza della complessità, ingegno e attrazione dei talenti.

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1. Introduction to Artificial intelligence

Fantastic expectations but also existential anxieties are two of the conflicting feelings that often arise in the general confusion of discussions on AI. The aim of this article is to provide a concrete and understandable picture of the AI situation and its possible developments, in particular focusing on how to make Italy a leader in AI. Let's start with the two examples concerning the authors. On the one hand, we have the case of a scientific and entrepreneurial activity in the field of machine translation. This requires the use of large neural networks and the input of a huge amount of data, in the spirit of ChatGPT and similar methods. On the other hand,

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we have the problem of making economic analyses of countries'growth more scientific and accurate. This requires a careful selection of a few selected data and the introduction of a new dedicated algorithm from which a better analysis of the growth of countries is obtained than that of large traditional economic institutions. Two very different and apparently conflicting cases with respect to the use of data, many or few, from which, however, one can extrapolate a varied and fascinating overall picture, of which we have only seen the beginning. A joint hybrid scheme then makes it possible to assess the impact of AI on the labor market based on actual investments rather than opinions. Finally, we will try to draw precise and realistic conclusions on how to best use the opportunities of this epochal revolution for Italy.

A bit of AI history and the invention of the wheel

Talking about Artificial intelligence immediately evokes an analogy with the human brain. Over the past fifty years, neurophysiology has allowed us to develop a detailed knowledge of the brain from a morphological point of view. This, however, has not yet led to a complete understanding of its functioning, which in many respects is still a mystery. It is a very complex network whose sites are represented by neuronal cells or neurons and the links are the synapses. In a brain there are about 100 billion neurons and 150 trillion synapses. The number of synapses per neuron can vary from 5,000 to 100,000, an incredibly high figure that gives an idea of the enormous complexity of the entire network. How intelligent thought can arise from this raw material is one of the most fascinating mysteries.

Compared to the specific properties of individual cells, great progress has been made, but the vision of the collective functioning of the system remains mysterious in many respects. Neurons behave a bit like switches that can be activated or be inert. When a neuron is activated, through an appropriate electrical stimulus, it generates an electrical signal that is transmitted to the synapse. This releases chemical messengers, neurotransmitters, which activate the receptors of the other connected neuron. This signal is converted into an electrical impulse and, through the synaptic network, can activate other neurons. These signals can be stimulators or inhibitors. A neuron generates a weighted sum of incoming binary signals coming from other neurons to generate an output binary signal.

An important element was then to realize that memory in the brain is associative in nature. In traditional computers, memory is addressed in specific places with a unique address, while in the brain even partial information allows you to get to the right concept. For over fifty years, we have tried to mathematize the behavior of neurons to try to artificially reproduce brain activity, but it was only in the 1980s with the work of Hopfield and Hinton (The Nobel Committee for Physics 2024) that a qualitative leap and the development of modern Neural Networks took place. This associative nature of memory, together with the binary functioning of neurons and synaptic connections, have inspired analogies with the models of Statistical Physics and the related concepts of energy, temperature and entropy. In particular, the complex energy structures of these models made of valleys and mountains have provided a possible interpretation of associative memory. If a given configuration of the entire system corresponds to a precise concept, entering an approximate concept into the system corresponds to being close to this energy minimum and, by appropriately relaxing the system, the correct result will be obtained even starting from partial information.

This analogy with Statistical Physics and, in particular, spin glasses (The Nobel Committee for Physics 2021) is at the basis of the introduction of Neural Networks, which can be of various types and correspond to an emulation of the properties of the brain that has associative memory and other important conceptual analogies. Of course, as with the natural brain, a long process of experience and education is necessary, and these networks also need to be trained with appropriate data. All this has led to increasingly interesting developments in recent decades, up to the current explosion of interest in generative AI and Large Language Models (LLM). Of course, trying to artificially reproduce intelligence based on analogies with the human brain is fascinating and certainly very valid. After all, the brain originates from Darwinian evolution, which is generally a very effective mechanism for finding ways to perform certain functions.

But it is also legitimate to ask whether this is necessarily the only method. Many of man's inventions are in fact inspired by nature but not all of them. For example, the wheel is one of the main inventions of humanity, but it is not present in any natural organism. We can therefore ask ourselves if, in addition to trying to replicate the structure of the brain, we could invent other concepts and structures that have not been explored by Darwinian evolution.

The invention of the wheel is attributed to the Mesopotamian civilization around 3400 BC and then to China. But suppose that these brilliant ancestors of ours, to improve transport, had been inspired by living beings such as people and animals. They would have tried to build robots to replicate their movements but clearly, with the technologies of the time, they would not have gone far. On the contrary, by observing the rolling of the trunks they used them to slide heavy objects such as stones for the pyramids. Then came the remarkable idea of taking only one section and inserting an axis passing through the center and thus the wheel with the central axis was born, one of the most important discoveries of humanity. Why do we mention this example? Because it is often assumed that the only way, or at least the best way, to extract information from a large amount of data is to emulate the human brain. In fact, this is the result of Darwinian evolution with respect to this problem but, as with the wheel, it is not said that it is the only or always the best. It is interesting to note that the wheel is completely absent in the Darwinian evolution of any species, probably because all organisms that come from cells are inevitably connected topologically and cannot have separate parts that are part of the same individual. However, this observation stimulates us to think of different perspectives with respect to the emulation of the brain.

An example of an alternative situation is Google's Page Rank algorithm, introduced in 1996, which allows categorizing all Internet sites with a simple algorithm. The Internet is a complex network in the sense that it is highly heterogeneous, it was not designed by anyone and grows from the bottom with the addition of new sites without central control. Each site contains links to other sites, and the problem was to classify these sites according to their importance. A traditional way could be to study the information contained in each site, compare it, and then make a ranking on this basis. Clearly, this method would be extremely expensive and also subjective, but the main problem is another. If a site contains a lot of information we would be tempted to give it a high ranking, but if no other site points to this site, it means that this information is not considered interesting for the community to which it belongs. So, if we consider the links between the various sites and not the characteristics of the site itself, we have direct information from the experts of the community of reference. This situation poses a technical problem of non-locality in the sense that the connections that are important to evaluate a given site are not the outgoing ones that are easily verifiable, but the incoming ones that potentially depend on any other site. Moreover, the importance of a connection clearly also depends on the importance of the site from which it originates, and all this complex information must be treated in a self-consistent way. This seemingly very complex problem is solved brilliantly by Google's algorithm which is based on a simple process of diffusion on the structure of Internet sites. By examining this process with a stochastic simulation method (Monte Carlo type), it can easily be verified that the self-consistent relevance of a given site is connected to the probability that the diffusion process will transit through that site. In this way we obtain a ranking of all the sites of a certain community (defined by the question that we introduce in the system) in which the information defined by the connections of the sites of the community is exploited, without having to study the content of each site individually. This simple algorithm applied to the structure of the Internet produces a hierarchy of all the sites related to the question asked and has allowed the whole world to explore the network of Internet sites in an extremely effective way, as we can verify every day. For many, Google's Page Rank algorithm represents the true beginning of modern AI.

Interdisciplinarity and Complexity

What lessons do we take from this? First of all, we can ask ourselves which scientific discipline the Google algorithm belongs to. Clearly it is computer science, but also statistical physics and mathematics, and even a bit of biology, considering that the Internet develops with autonomous growth from the bottom. In other words, the Google algorithm, which has revolutionized all our information and produced one of the most important companies in the world, cannot be included in the context of traditional scientific disciplines. But this should not surprise us considering that Physics, Chemistry, Mathematics etc. were defined as such towards the end of the eighteenth century, after the Napoleonic reforms and the development of Enlightenment. But after three centuries the world is radically different and the scientific and social problems of today's world are completely different and transcend these disciplines. In fact, the Google algorithm was developed by two students in a garage and not in a prestigious academic institution. This should make us reflect on the importance of interdisciplinarity in trying to solve the great current problems and on the fact that overcoming disciplinary boundaries with dedicated institutions can be extremely interesting and important.

Finally, we see that Google is not based on a general Neural network but develops a specific algorithm for a specific problem. An interesting question is whether a suitable neural network, appropriately trained, could generate the same results without explicitly using the Google algorithm. In our metaphor, Google's algorithm goes more towards the invention of the wheel than towards the emulation of the brain.

The fact that these systems focus more on the connections between the various elements of the system and that from this strongly interconnected network emerging properties such as intelligence originate, leads us naturally to the field of Complex Systems Science. The article published in *Europhysics news* (Pietronero 2008) is a sort of Manifesto for the Physics of Complex Systems that inspired the foundation of the homonymous CNR Institute. This article proposes a suggestive metaphor according to which Particle Physics studies the *elementary bricks* of matter while the Physics of Complex Systems studies the *Architecture* of nature, focusing mainly on mutual interrelations and related emerging properties. Clearly this depends on the properties of the bricks, but then it has its own characteristics and fundamental laws that are not attributable to the bricks and require characteristic concepts and methods. It is also clear that this paradigm of Complexity can be naturally extended to interdisciplinary situations in which the bricks are not elementary particles but, for example, people or institutions as in the field of economics. The goal is to make these disciplines more scientific by using concepts and methods from the Physics of Complex Systems. One may object that in some fields it is difficult to do experiments. This is true also in Astrophysics, which is essentially an observational science but studied with the scientific method of Physics. Today, in Economics, we have a huge amount of data and therefore the application of concepts and methods from Physics can lead to an advancement of the scientific level in issues of the highest scientific and social importance such as the economic development of countries.

2. From translation to the future of AI

Machine translation has always been the most complex challenge for Artificial intelligence because language represents the deepest manifestation of human intelligence, rich in nuances and ambiguities that are difficult to replicate by a machine. In the 1940s, Alan Turing laid the theoretical foundations by translating the Enigma code, realizing that decoding messages was equivalent to a form of language translation. In the 1950s, the initial enthusiasm for the first translation machines quickly collided with the enormous complexity of natural language, highlighting insurmountable limitations for decades.

Only with the advent of statistical methods in the 1990s and deep neural networks since 2010 has machine translation improved significantly, culminating in the invention of the Transformer in 2017. This architecture, initially designed to overcome the limitations of language translation, has revolutionized the entire field of AI thanks to its ability to understand and generate texts with almost human quality. Today, Transformers (Vaswani *et al.* 2017), which were created to translate between languages, are the basis of ChatGPT, a system that 'translates' questions into coherent answers, demonstrating how machine translation remains the privileged ground on which to measure the progress of Artificial intelligence.

In recent years, Artificial intelligence has gone through three fundamental stages: initially, neural networks outperformed university students in answering notional questions. Subsequently, models such as ChatGPT have shown superior language and persuasive skills to almost all the same students. Since 2024, research has focused on enhancing logical reasoning skills through techniques such as Chain-of-Thought, with systems already approaching the logical abilities of doctoral students.

The human brain, used by many as the absolute reference of intelligence, is certainly the most sophisticated form we know, but there are no physical limits that prevent the creation of superior intelligences. However, the limitations of current techniques and data are also beginning to emerge clearly. These limitations represent a huge opportunity for new players, including Italy, to enter the market.

Current techniques are mainly limited in three areas:

- *Data*: today AI systems are mainly trained on textual data, ignoring the enormous potential of multimodal learning (for example, audio and video). An equipped machine, capable of processing from sensors superior to human ones, could develop innovative and more efficient learning methods.
- *Algorithms*: the current Transformer (Vaswani *et al.* 2017) architecture has limited learning and efficiency capabilities and lacks plasticity, i.e. the ability to modify its architecture, without human intervention, to adapt to evolving contexts of use. It is still 2-3 orders of magnitude more expensive in data and energy than the presumed practical limits and 5 orders of magnitude more expensive than Landauer's theoretical limit.
- *Computing*: the AI chip market (GPU) today has a strong monopoly, with economic barriers to entry, ecosystem constraints and high technological lock-in. Stimulating the creation and adoption of new chips could significantly expand access to innovation in AI and foster a more competitive and diversified ecosystem.

Taking advantage of these opportunities can position Italy as a key player in the development of the Artificial intelligence of the future.

3. Economic Fitness Data Science Paradigm for countries'development

Economic Fitness and Complexity (Pietronero *et al.* 2024) (EFC) is the recent economic discipline and methodology initially developed at Sapienza University of Rome and ISC-CNR and now at Centro Fermi (www.cref.it) together with several collaborators from various institutions. EFC uses and develops modern data analysis techniques to build economic models based on a scientific methodology inspired by Complex Systems Science (Pietronero 2008) with particular attention to quantitative tests and specific forecasts that provide a solid scientific framework. It consists of a scientific and algorithmic approach that considers specific and concrete problems without economic ideologies and acquires information from the previous growth data of all countries with Artificial intelligence methods, in particular Complex Networks, Algorithms and Machine Learning. Its main features are scientific rigor, precision in analysis and forecasting, transparency and adaptability. The Fitness algorithm overcomes the conceptual and practical problems of the first attempts in this field, and lays the foundations for a testable and successful implementation of the field of Economic Complexity. In particular, it attributes the right importance to the fundamental concepts of diversification and complexity of products. Fitness is in fact defined as the diversification of products weighted by their Complexity (Tacchella *et al.* 2012; Cristelli *et al.* 2013) and the new algorithm allows to obtain both the Fitness of all countries and the Complexity of all products. Diversification characterizes the variety and therefore the stability of the economic system while the complexity of the products describes their technological level and the exclusivity that are connected to the added value and profit. EFC also represents a fascinating and effective bridge between the methods of hard sciences and the problems of the humanities, social sciences and economics. It allows us to tackle some of the most important problems of humanity such as the development and industrialization of countries from a new scientific perspective with concrete results directly useful for progress.

The ideological debate on which is the best theory for economic development is replaced by a new paradigm. There is no ideal theory valid for every situation. As in medicine, where one must first analyze and identify the disease and then decide on the appropriate therapy, there is no universal medicine valid for all diseases. Similarly, there are no universally valid development criteria for the economic development of a country. The various strategies are intrinsically dependent on the context and will vary according to the economic characteristics and circumstances of each country. It is easy to verify from historical data that, for example, the application of neoliberal concepts, i.e. leaving everything on the market without government industrial policy, has been unsuccessful in many cases. But even in those countries where there has been industrial policy, the results have been mostly disappointing. The problem is that they tried to adapt the same criteria to very different situations.

The EFC methodology allows for a detailed analysis of each country at a given time, defines its industrial competitiveness for each sector and identifies possible realistic development trajectories. These can be different, more or less ambitious, and for each of them it is possible to define the probability of success and the relative increase in production complexity and therefore of the overall Fitness (Tacchella *et al.* 2023). These concepts have interesting similarities with the New Structural Economics by Justin Lin (2014), former Chief Economist of the World Bank in Washington and now at the University of Beijing and also have some affinities with the theories developed by Mariana Mazzucato of London. From the Data Science point of view, the EFC methods are complementary to the NSE economic theory and according to Justin Lin: "Our dream is that this collaboration will lead to sustainable economic development and a world free from poverty".

The EFC methodology allows a radically new approach to the issue of forecasting GDP growth, which represents a benchmark for the quality of the analysis. The review of GDP in the medium to long term is in fact a notoriously difficult problem even for the most competent institutions. The EFC method bases its forecasts on the flow trajectories of countries in the new space defined by GDP (per capita) and Fitness and uses the methods of Dynamical Systems Physics. The result is better than that of the International Monetary Fund (IMF) of Washington (Cristelli *et al.* 2015; Tacchella *et al.* 2018). In fact, after a detailed analysis, Bloomberg concluded that: "New research has demonstrated that the 'fitness' technique systematically outperforms standard methods, despite requiring much less data". Note the emphasis on the fact that few data are used.

In fact, the IMF has about 2,000 people dealing with this problem and, in general, there is a team for each country that uses country-specific analysis criteria. Then there is the core team in Washington that tries to harmonize all these analyses. Clearly, all available data is used in these analyses but, as we will see below, this can lead to advantages and disadvantages. Furthermore, such a method is inherently characterized by subjective elements and is therefore difficult to reproduce or test in a scientifically independent manner. Another element of the EFC method is that it can correctly explain and predict the fantastic development of China over the past forty years (Pietronero *et al.* 2025). A fact that has eluded most experts and traditional methods. Finally, Fitness appears to be a much more appropriate criterion of validity for the development of countries than GDP and has been adopted for the analysis of IFC-World Bank projects, EU NRRP projects and London EBRD projects.

Big Data, opportunity and myth

The immense accumulation of data is a new phenomenon that induces many considerations, represents great potential and also leads to mythical expectations. A few years ago, it was even suggested that if you have enough data, you can do without theories and traditional understanding. This extreme view now seems to have waned and has been replaced by Large Language Models. The basic idea in these models is to catalogue an immense number of texts on a neural network that provide the basis of their knowledge. At first, the criterion for training was extremely simple and consisted in guessing the missing word in a text. With the Transformer, a fundamental step forward has been taken and, in addition to reproducing and summarizing texts admirably, LLMs have begun to answer questions in an almost unexpected way. Recently, this trend seems to be moving even towards a sort of 'reasoning'. Many of these features were not anticipated by the developers themselves and were quite surprising. It therefore seems that when the system reaches an enormous complexity, emergent behaviors are spontaneously activated. A fascinating problem from the scientific side in which the Science of Complexity seems to be the appropriate context for their understanding.

This approach is typical of Big Science, since the amount of data needed and the related energy and costs can be astronomical, even in the order of billions of euros.

However, we have also seen complementary situations, such as the Google algorithm, developed by two students in a garage and the Fitness algorithm in which even the data must be carefully limited and selected. However, this method gives superior results to the main economic institutions that certainly use all available data. How is this apparent paradox possible? First, it should be considered that we are now trying to answer a very precise scientific question, albeit a far-reaching one. This answer is clearly not contained in the data available even in the most powerful LLMs as we are really trying to increase our knowledge.

The standard analysis of countries 'competitiveness considers a series of elements such as education, finance, transport, production, export, pollution etc. and with an adequate weighting of these elements leads to an overall score for the country. In the end, this analysis requires defining over 100 parameters to assign the weight relative to all these elements, each of which is in turn characterized by a large amount of data. Clearly, this is a task that introduces subjective and ideological elements and that cannot adequately consider all the possible interactions between these elements. Furthermore, the analysis is carried out for each country individually and only at the end are different countries compared.

The Economic Complexity (EFC) (Pietronero *et al.* 2024) method corresponds to a change of perspective that goes beyond individual analysis. All countries are considered as nodes of an integrated network, and the connections are given by the products they produce. In practice, we consider the bipartite network of countries and products, and the idea is to extract interesting information from the general properties of this network in the spirit of the Google algorithm, although, as we shall see, a different algorithm is needed here. The first problem is that consistent and homogeneous data are needed for all countries, but they are usually not available or are only partially available. So, the new vision immediately shows the limits of the available data. It is a qualitative problem, not dependent on the amount of data. So, we start working with what is available, but we would like to have something else. For example, it would be very useful to have complete information for all countries of the work activities, but this data is not currently complete, so we use the data of the exported products for which we have complete and homogeneous information as a proxy for competitiveness.

In principle, clearly you have more information than simple products, but the problem is that these data are not independent and considering them all together only leads to confusion or an intrinsically subjective interpretation, as it requires assigning parameters and weights to the various data. But we wanted to go beyond this phase and do a scientific analysis, that is, provided a unique, reproducible result that was not dependent on subjective interpretation. This leads to a selection of the data and to a drastic reduction of the same. Only a selected subset is really useful (Lin 2014; Cristelli *et al.* 2015), adding more data would lead to a sort of confusion.

This discussion is analogous to Poincaré's studies on predictability in dynamic systems, which is high if the dimensionality of these systems is low. In some ways, having data in many directions is similar to having a high dimensionality. Therefore, increasing the data increases the information but also the mathematical noise or, in a more colloquial way, the confusion. In the case of Fitness, it has been shown that the optimal situation is with data appropriately selected with respect to the homogeneity criteria. Here we are clearly in the field of Small Science, which requires a specific culture to be developed in the field of Complex Systems Science.

It is easy to imagine that many of the open scientific problems in various fields where a lot of data is available, in particular, for example, in medicine, can have considerable advantages from algorithmic approaches similar to Economic Fitness. As we have seen in situations of this kind, a specific and targeted approach to the problem to be considered is necessary. This is a qualitatively different problem from the use of LLM models as the goal is to obtain new information that is not contained in the dataset with which the network was trained. These types of developments have the characteristics of Small Science and would seem particularly suitable for Italy as they depend on ingenuity and creativity, typical of Small Science, rather than on brute force or material resources.

4. The impact of AI on the world of work

This is a typical case where analysis and forecasts are enormously divergent. Some think that human work will be almost entirely replaced by AI and robots and envision apocalyptic scenarios with a huge number of unemployed people and a few owners of these technologies that will upset and dominate the world, while others see in AI a great help and support to many activities that will become easier without eliminating employment.

Let us try to learn some lessons from some specific cases of innovations that have produced disruptive developments. In 1997, Kodak had about 160,000 employees. And about 85% of the world's photography was taken with Kodak cameras. With the rise of digital cameras in recent years and now even with photos from cell phones, Kodak has completely failed, and all its employees have been laid off.

Many other more recent examples can be made, such as Nokia, which at one point was a leader in mobile phones and has now disappeared. The curious thing about Kodak, and perhaps not well known, is that Kodak itself had a research group that contributed to the development of digital cameras but, since the dominant industrial culture was that of chemistry, the digital line did not have much following.

In the early 1980s, IBM developed the first Personal Computers, but the dominant culture was that of large mainframe computers and the PC was considered little more than a toy. It is from this perspective that the operating system of IBM PCs was contracted and practically given to Bill Gates who made his fortune.

Finally, in the 1970s, Xerox developed the graphical interface without realizing that this would lead to the Mouse with all its related developments. This technology was then given to Steve Jobs with the consequences we all know. Even Xerox is now a pale memory of the great innovative company it was many years ago.

These examples show that a certain culture and business tradition can represent a brake on innovation and that innovative companies must be ready to question themselves continuously to seize the technological opportunities that they themselves have sometimes developed. The situation of Nokia is quite different because, if on the one hand it was impossible to predict that a group of brilliant Finnish engineers would develop a particularly efficient mobile phone, on the other hand it was possible to predict, with the methods of Economic Fitness, that the evolution from the simple mobile phone to today's smartphones would have been problematic for Nokia. In fact, this step implies that the phone is integrated with many other technologies, and these were certainly present in the industrial ecosystem of Silicon Valley but not in Finland.

Returning to the question of the impact of AI on the world of work, some predictions are reasonably realistic while others are very difficult. For example, it is very difficult to predict which new activities can be developed and invented, because the potential of these new methods is in tumultuous development and therefore the best thing is to stay informed about these developments, and their possible consequences.

The problem of the impact of AI on existing work activities is different and much more manageable. Also, for this case, opinions and expectations are quite different. However, here we can develop an original contribution that uses both the Fitness methodology and the LLM models in an interesting combination (Fenoaltea *et al.* 2025).

Each work activity is associated with a certain number of skills or abilities that are necessary to carry it out. All work activities and related skills are codified by international organizations and the data are public. Looking at these data, we can observe that some activities require many skills, then progressively others require fewer skills, up to some that use very few. The mathematical nature of this data distribution is *nested*, quite similar to that between countries and products that stimulated the development of the Fitness algorithm. Using this algorithm we then obtain the Fitness of all work activities and the Complexity of all skills. For example, one of the activities with the highest Fitness is that of an airplane pilot, as it requires many skills, some of considerable complexity. An opposite example of activities with low Fitness is that of the model, which requires very few skills.

Then there are data that estimate the impact that AI will have on each skill. These data are of a subjective nature, obtained by interviewing experts. By combining all this, we can then obtain the estimated impact of AI on each work activity. The general trend is that the greater the Fitness, the lower the impact of AI. This trend is understandable because, if you have many skills and perhaps even complex ones, it is difficult for AI to have a great impact on all these skills.

But let's also observe some peculiarities and notable outliers. For example, some activities that would be said to be of a certain complexity such as those of physicists, mathematicians and computer scientist have a low Fitness and therefore a high impact expected from AI. This is due to the fact that the skills classified at the moment correspond mostly to manual and practical activities, while conceptual ones are relatively few. This anomaly can be cured by increasing the skills of intellectual activities in order to balance the distribution and we are working on this improvement.

Regarding the outliers, the airplane pilot who has the highest Fitness is quite replaceable with AI. This is due to the fact that, although it is complex to replace a pilot, there is a great effort and desire to do so using drones.

An opposite case is that of judges, who in theory are easily replaceable using an LLM model that learns all the laws, compares them with the crimes committed and produces the sentences. However, the idea of replacing a judge with AI does not appear socially acceptable. This is why AI will not have much impact on these activities, despite the theoretical possibility of doing so.

We have therefore seen that considering only the theoretical and subjective impact of AI on the various skills is not very realistic. It is much more appropriate to consider the investment that is actually made for these substitutions. We therefore considered a series of start-up companies, and, through LLM methods, we compared their activities with the definition of the various skills. In this way, we obtain a criterion of substitutability or impact of AI based on the investments that are actually made rather than on theoretical and subjective opinions. In this way, we obtained an index of the impact of AI on skills, and therefore on work activities, which at the moment presumably represents the state of the art in the field (Fenoaltea *et al.* 2025).

5. Comparison between LLM analyses and the creation of new information

We have seen that LLM models are based on neural networks that emulate the architecture of the brain, are of a generalist nature, and require enormous amounts of data and energy. In 1996, Google's Page Rank algorithm made it possible to define a hierarchy of all Internet sites connected with the question that arises. Now with LLM, we can enter the content of these sites and acquire all the information (text) they contain, which is then appropriately stored. In principle, all the public information in the world will soon be stored. With Transformer and subsequent developments, a further step is taken that allows for high-quality reasoned summaries. What is surprising, however, is that these systems seem to go even further and become capable of answering questions, which were somehow not foreseen in the original programs. Furthermore, it is observed that the ability to answer some specific questions, for example in mathematics, becomes possible in a discontinuous way only after the acquisition of billions of data. These phenomena appear as emerging and indicative of a certain '*reasoning*' ability of these systems, which were initially trained only by the criterion of adding the missing correct word to a text. At the moment, it is difficult to have a clear idea of where we can get through these developments and in what sense we can talk about the emergence of elements of creativity.

On the other hand, we have seen a qualitatively different example with Economic Fitness. In this case, we are faced with a very precise and well-defined problem, albeit far-reaching, which is how to plan and predict the economic development of countries with data-driven scientific methods. Curiously, here it is important to limit the data to the most significant ones and invent a new algorithm. Then a new space is introduced to analyze the dynamics of countries and from this, with methods inspired by Physics, it is possible to make analyses and forecasts that are superior to those of standard institutions that use much more data. In this case, however, we are using existing data as a basis for acquiring new knowledge with a new method that cannot be found in the existing literature, so it is natural that LLM models cannot reproduce these results that correspond to the acquisition of new knowledge.

However, considering the elements of creativity that we discussed earlier, it is legitimate to ask whether in the future LLM models will be able to autonomously develop concepts and methods that do not currently exist. Innovation often consists in combining different technologies that had not been combined before, such as in autonomous driving. It is reasonable to think that this type of innovation may one day be within the reach of LLM models. For more radical innovations such as Economic Fitness compared to standard economic models, the situation appears more difficult, but it is unwise to be too drastic with these arguments because this field has already accustomed us to surprising and unexpected developments.

At the moment, we can conclude that the development of general methods of the LLM type seems associated with large investments and large energy capacities, although the Chinese company Deepseek seems to have brought significant improvements in efficiency.

In a complementary way, the exploration of scientific problems based on Data Science seems to require a specific creative effort whose results are not reproducible by LLMs. For example, if we compare our results of the impact of AI on the labor market reported in Fenoaltea *et al.* 2025 with the same question asked to ChatGPT, it is easy to realize that our new results are far superior to what can be achieved with ChatGPT at the moment.

In conclusion, the development of generalist LLM methods seems to belong more to Big Science, while the development of new scientific knowledge, beyond the current one, requires ingenuity and creativity that seem closer to the culture of Small Science.

6. What Italy has already done in AI

Italy has developed an AI ecosystem with discrete contributions in both research and industry. National academic research is of a high standard: in 2022, the country produced 3,261[1] scientific publications on AI, ranking seventh in the world. Several centers of excellence participate in European AI projects (Italy is involved in 12% of EU projects). On the private side, the Italian AI market is growing rapidly, reaching about 1.2 billion euros[2] in 2024 (+58% in one year).

However, the entrepreneurial fabric remains fragmented: there are only about 600 patents by Italian inventors and just over 350 AI startups founded since 2017, a figure that places Italy at the bottom of the list in Europe. The government has launched a National AI Strategy and targeted initiatives (e.g., the FAIR foundation with 28.7 million from the PNRR) to stimulate innovation. Critical issues remain: the difficulty in retaining specialized talent and the absence of global industrial champions in the sector. At the international level, Italy's strengths and weaknesses compared to AI leaders are highlighted. The United States and China dominate thanks to massive investments and technology giants: in 2022, the U.S. registered over 16,000 AI patents, compared to less than 800[3] in the entire European Union. But China seems to be doing even better. Considering the patents approved in the field of AI, 61% are Chinese, 21% US and only 2% EU and UK. The UK and France have ambitious strategies and centers of excellence: the former was the cradle of DeepMind, the latter announced a 109 billion euros plan for AI. Italy can count on quality scientific research and participation in European programs, but it suffers from the lack of global industrial champions and advanced computing infrastructures (the lack of data centers and supercomputers is a significant obstacle). The Italian AI landscape is lively, but it needs to accelerate to bridge the gap with leading countries by strengthening investments and skills.

7. How to make Italy a leader in AI

We have discussed the origin and the tumultuous development of AI in recent years that show unexpected and almost mysterious emerging properties. The field is fascinating both from a purely scientific point of view and for the impact it will have on work activities and on the whole of society.

From a scientific point of view, it is important to create an interdisciplinary culture that allows an original approach, appropriate to this field. Certainly, the Physics of Complex Systems appears as an appropriate context to try to define a cultural and scientific framework for the many features of the AI field. From the methodological standpoint, we have discussed situations that require huge amounts of data and energy but also those in which fundamental contributions can be made by two students in a garage, like in the case of Google, but also for the economic Fitness algorithm in which the drastic reduction of data was actually essential. Clearly there is room for both these extreme situations and also for all those in between.

This situation recalls the dichotomy between Big Science and Small Science in Physics. On the one hand, Big Science can be planned and involves the development of large laboratories that have great media and political visibility. On the other hand, Small Science often concerns situations that

1 Strategia italiana per l'intelligenza artificiale: facilitatori per le imprese e sostegno alle startup, Manuela Perrone, in *Il Sole 24 Ore*, 22 luglio 2024, https://www.ilsole24ore.com/art/intelligenza-artificiale-facilitatori-le-imprese-e-sostegno-startup-AFl7EyzC.

2 Intelligenza artificiale, boom del mercato italiano: +58%, 1,2 miliardi di euro, *Polimi School of Management*, February 2025, https://www.osservatori.net/comunicato/artificial-intelligence/intelligenza-artificiale-italia/.

3 Il ritardo dell'Europa nell'intelligenza artificiale: numeri e sfide, Biagio Simonetta in Il Sole 24 Ore, 23 agosto 2024, https://www.ilsole24ore.com/art/la-sfida-sull-intelligenza-artificiale-ecco-numeri-ritardo-europeo-AF6470UD.

are not very predictable and plannable and that individually are less spectacular. But in science one wants to explore an unknown area and therefore evaluating it carefully with known criteria can be very problematic. In fact, many of the discoveries in the field of Small Science are unexpected and difficult to evaluate a priori. It should also be noted, though, that Nobel prizes in Physics are much more numerous in Small Science than in Big Science. Also, in the context of AI, these apparently opposite trends are well identifiable and are actually complementary. Both should be cultivated with care and efficiency without deluding ourselves that size and power are the only keys to success. In particular, Italy can hardly compete in the context of AI Big Science, while the development of a Small Science culture for AI, which has excellent prospects for being competitive at the highest level, appears much more realistic and appropriate.

From an educational standpoint, it is important to train a generation of young scientists who can make an original and creative contribution to the field of AI combined in various areas and disciplines in an interdisciplinary context. The development of LLM techniques and those that will follow will involve a limited number of specialists. But the use of these techniques in all fields, both industrial and scientific, will involve a much larger number of people. A broad cultural investment must therefore be made in this direction.

Below is a preliminary analysis but, in case of interest, it would be very easy to produce a 3-month study with a larger research group.

Economic Complexity teaches us that the higher the Fitness of an ecosystem, the higher its growth potential. Fitness is high when an ecosystem has internally everything that is necessary for success without having to purchase goods and knowledge from the outside because this would lead to a slower speed in adopting innovation.

Artificial intelligence requires the following resources and skills:

Resource / Expertise	Prevailing Investment	EU	USA	China
Raw materials for chip construction	Infrastructure	Poor	Good*	Excellent
Chip design	Human capital	Poor	Excellent	Good
Lithography for semiconductors <=2nm	Infrastructure	Excellent	Poor*	Poor*
Chip manufacturing <=2nm	Infrastructure	Poor	Poor*	Excellent
Chip assembly	Infrastructure	Poor	Poor*	Excellent
Hardware acceleration software	Human capital	Poor	Excellent	Poor*
Datacenters for training (cold climate and basic energy)	Infrastructure	Poor	Good	Good
Global datacenters for inference (latency, base energy)	Infrastructure	Poor	Excellent	Good**
Basic research on AI	Human capital	Good	Excellent	Excellent
Risk Capital (All stages)	Human capital	Poor	Excellent	Good
Creation of Foundational Models and access to data	Infrastructure	Poor***	Excellent	Excellent
Creation of Vertical Models	Human capital	Good	Good	Good
Creating AI Applications	Human capital	Good	Excellent	Excellent
Integration and Platforms	Human capital	Good	Excellent	Excellent
Go-To-Market and Company Scale-ups	Human capital	Poor	Excellent	Good
Protection of Dominant Positions (M&A, Investments, Lobbying)	Human capital	Poor	Excellent	Good

* Indicates that the rating could improve rapidly thanks to investments already made. The US, with the CHIP Act, is investing in chips and alternatives to EUV lithography. They have also entered into direct agreements with Intel, TSMC, Samsung, TI and others.

** China was rated good and not excellent because the US does not allow Chinese companies to enter the US market easily.

*** In addition to infrastructure investments, profound regulatory changes are needed. Mistral, the only foundational LLM player, has investments orders of magnitude smaller than its US and China competitors.

For human capital it is good to note that Italy potentially has good access but the flight of junior and qualified talent (550,000 talents lost in the last three years according to the CNEL study) makes the country absolutely devoid of the necessary resources. Furthermore, lacking the qualified ecosystem, the talent that remains grows in skills at a lower speed and totally lacks the more senior and managerial figures who today have only been trained abroad.

It seems clear that limiting the brain drain, aggressively repatriating senior talent and becoming more attractive than the US and China for global talent is the only way to have an opportunity.

Attracting talent is given by several elements but the most important are:

- *Values*. Prove to be a country that appreciates young talent and creates more favorable and even less restrictive research and application conditions between the US and China. Today the critical issue is that Italy has always sent the opposite signal, making regulations against digital and innovation, mainly protecting the status quo. And this requires perhaps the most profound and difficult change to achieve.
- *Infrastructure*. Make the infrastructure investments necessary to increase fitness.
- *Public Research.* Create a job offer that is economically and socially more convenient than the American and Chinese ones. Here the critical issue is that AI talent today is worth and is also paid an order of magnitude more than the average. The critical issue is to bring together researchers who earn 25,000 euros a year with those attracted who will necessarily earn 250,000 euros a year.
- *Private Human Capital.* Provide incentives to businesses to bring back talent. The critical issue will be that the private market will want to invest only when the market is clear, thus creating a stalemate.

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