# The Hubbert game: a simple board game designed to teach the dynamics of the overexploitation of natural resources

**Ugo Bardi**

Dipartimento di Scienze della Terra, Università di Firenze
Polo Scientifico di Sesto Fiorentino
Via della Lastruccia 3, 50121 Sesto Fiorentino, Fi, Italy
ugo.bardi@unifi.it
+39 055 457 3118

## Abstract

This paper describes a simulation of the dynamic process of resource overexploitation in the form of an operational game. It is based on the transformation of a simple system dynamics model into a boardgame, conceived in order to provide students with a hands-on experience that may help them to understand the basic features of the dynamic approach to overexploitation. In particular, the game reproduces the phenomenon known as the “Hubbert Curve” which is an approximation of the results of system dynamics studies of economic systems where the resources being exploited are subjected to overexploitation. The game requires no computers and no special equipment. It can be played by three to four teams for a game time of one-two hours. This exercise has the purpose of familiarizing students with the dynamic mechanisms of overexploitation and to allow the students to understand how non-linear phenomena may affect economic systems.

## 1. Introduction

Games have a long history as methods to simulate complex systems. These systems are characterized by interacting feedback loops that make their behavior non linear; strongly reacting to even minor changes in some parameters. Hence, the need of methods of study that capture their rapidly changing behavior and their unpredictability. Almost any system can be transformed into a game and games are often used for the purpose of training students with a hands on approach in areas such as military simulations (wargames) and business games. In this form, they are often called “operational games”.

The ecosystem is a typical non-linear system dominated by feedback effects and it is often studied by the method called “System Dynamics” (see, e.g. (Forrester 1989), (Richardson 2013)) which emphasizes the feedbacks among the various elements of the system. However, practical experience shows that students engaged in learning these matters have serious difficulties in understanding a formal approach to system dynamics, as well as in evaluating the system's behavior. This problem was shown in several studies, e.g. (Sweeney and Sterman 2000) (Cronin et al. 2009). Hence, much teaching work is performed using operational games with the hope of providing a hands-on experience for students. Dennis Meadows commented on this point by citing an an ancient saying, “*When I hear, I forget. When I see, I remember. When I do, I understand.*” (Meadows 2007).

A well known operational game in system dynamics is the “beer game” developed by Jay Forrester in the 1960s (Hieber and Hartel 2003). Operational games also exist in the field of the management of natural resources, for instance the “fishbanks” game, created by John Sterman and Dennis Meadows and dedicated to fishery management (Crookhall 1990). Games can also simulate a whole economy, such as in the “Stratagem” game (Sterman and Meadows 1985). In the present paper, I will describe a simple operational game that aims at generating the behavior typical of the management of a natural resource when it is exploited at a rate faster than it can reform, a phenomenon called “overshoot” (Catton 1982) or “overexploitation.” I am calling this game “The Hubbert Game” in honor of Marion King Hubbert, the first to develop a general concept of the cycle of exploitation of a mineral resource (Hubbert 1956), see also (Hemmingsen 2010). The Hubbert model has often been seen as a predictive tool, but the approach of the present paper is not limited to mineral resources and it aims at describing the more general concept of overexploitation of natural resources following the system dynamics approach used already in 1972 in the study titled “The Limits to Growth” (D. H. Meadows et al. 1972), and in later studies (e.g. (Meadows et al. 2004) ) and also by simple “mind-sized” models (Bardi 2013) .

These models tend to generate “bell shaped” production curves that are often (although by no means always) observed in the historical record. The “Hubbert game” was developed with the idea of creating a simple, nearly zero-cost operational game which can be seen as an introduction to the full treatment of the system dynamics approach to the problem of overexploitation. The game presented here is the result of an evolving effort which, I believe, has reached level of testing that allows it to be publicly described. The author hopes that further and more comprehensive testing may be performed by others and by himself.

## 2. Overshoot and resource depletion

This section describes the current status of the issue of overshoot and, in particular of the depletion of mineral resources. The question was scientifically approached for the first time by William Stanley Jevons in his “The Coal Question” (Jevons 1866). Jevons identified the main elements of the depletion cycle, namely how the exhaustion of high yield resources would progressively hamper the capability of the economic system to maintain high extraction rates. Over the course of more than a century of studies, the field has much progressed both in terms of the availability of data and in terms of the theoretical work performed on them. The optimistic side in this debate may be represented by the “Austrian School of Economics” (for a review, see e.g. (Bradley 2007)) and in rather extreme form in the work by Julian Simon (Simon 1981) . Qualitatively, the optimistic approach can be described on the basis of the early work performed on the concept of “resource pyramid” which is common in many publications on the subject. The model accepts the fact that the gradual depletion of high grade ores will make the production of mineral commodities. However, it argues that the market can adapt to this gradual phenomenon, since increasing prices of the commodities will lead to larger investments in extraction. At the same time, these investments will lead to more technological progress which will lead to a lowering of the extraction costs or to the development of alternative resources. The possibility of “infinite substitutability” of rare minerals was discussed for the first time in (Goeller and Weinberg 1978), as well as in more recent papers with various degrees of optimism (see. e. g. (Ayres 2007).

The pessimistic side, in its modern form, can be described in qualitative terms as emphasizing the limited extent of the extractable resources, while at the same time noting that technological progress cannot supersede the laws of thermodynamics (Valero and Valero 2014). This viewpoint is not limited to mineral resources but it deals with all cases in which a resource (even a renewable one) is exploited faster than it can be recreated by natural processes. In this sense, studies go back to the well known “Tragedy of the Commons” described by (Hardin 1968). There are several cases of theoretically renewable resources that have been exploited so fast that they behaved as non-renewable ones; for instance the North American Buffalo or the whale fishery in the 19th century

(Bardi 2007a). In the case of mineral resources, the first modern approach to depletion was the model developed by the American geologist Marion King Hubbert in 1956 (Hubbert, 1956). In the original version, the model dealt only with oil production in the US 48 lower states, assuming that it should have followed a “bell shaped” curve. Hubbert never detailed the mathematical basis of his model, which appears to have been mainly empirical. In general, the bell shaped curve seems to be a common feature in the history of major oil production regions (Brandt, 2007), even though it is not by any means a “law” as commonly intended in physics. The shape of the curve it is often masked by market factors or government regulations and it can be affected by technological factors or geopolitical events such as wars and political changes. Nevertheless, the bell shaped curve, although not necessarily a symmetric one, is a common feature of many economic systems based the exploitation of a non-renewable or slowly renewable resources. It can be often observed, for in instance in the case of fisheries. Two examples are shown here; one for a non-rewable and one for a renewable resource.

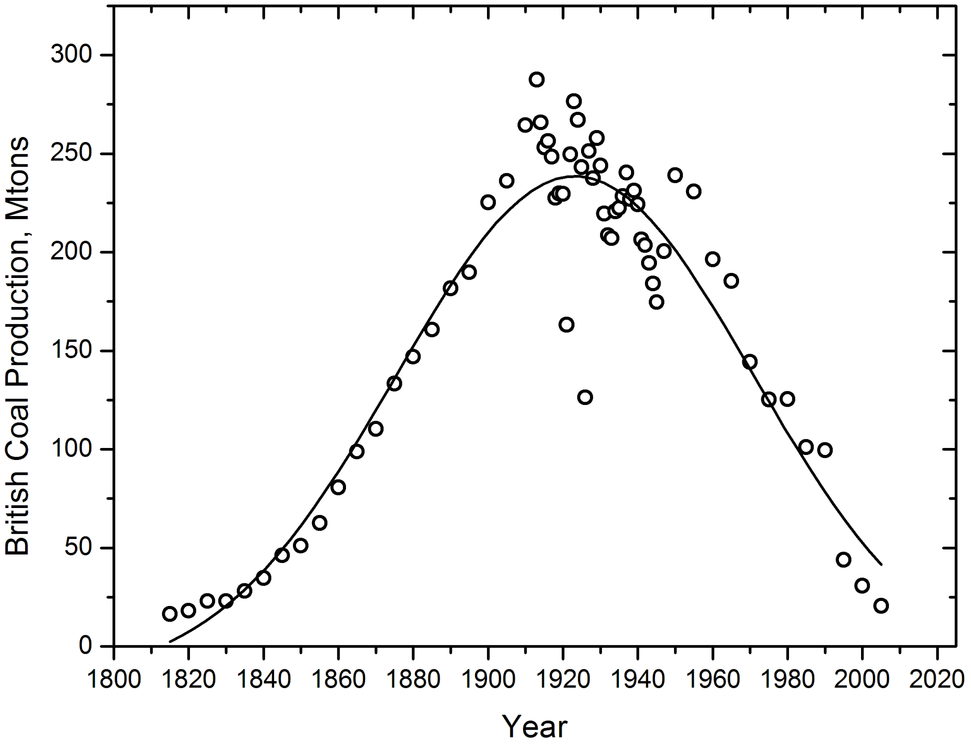

Figure 1. The production cycle of British coal from 1800 to 2004. The data up to 1860 are from (Cook and Stevenson 1996). From 1860 to 1946 are from (Kirby 1977). The data up to 2004 are from the British coal mining authority (2006). The data have been fitted with a Gaussian function.

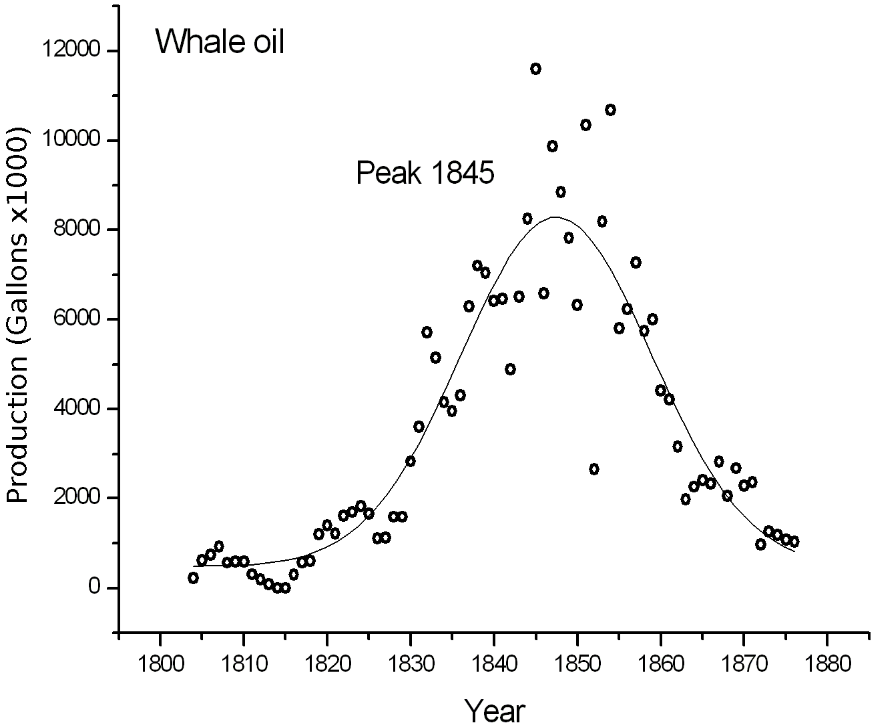

Figure 2. This image shows the production of whale oil in the United States in the 19th century. The data have been fitted with a gaussian function showing how overexploitation can be observed also in the case of a theoretically renewable resource, when it exploited much faster than it can reform. The data are from Starbuck's book "History of the American Whale Fishery" (Starbuck 1989). Details on this system are reported in (Bardi 2007b).

## 3. The system dynamics approach to overshoot and depletion

Qualitatively, the behavior of a system undergoing overexploitation can be described in a narrative form. We can start by noting that, during the initial phases of the exploitation of the resource, firms tend to invest a constant fraction of their revenues into more exploitation; e.g., in the case of an oil company, into more exploration and drilling. If the return on the investment remains constant, the result is an exponential growth of the production of the resource. This behavior is analogous to that of a biological species reproducing in the presence of abundant food. However, in the case of overexploitation, the resource is consumed faster than it can reform and it becomes gradually rarer to find. Consequently, the return on investment diminishes and growth slows down. As this process keeps going on, returns become so small that the industry can't finance any more further growth of its production. As a result, the production will start diminishing and eventually vanish to zero, after having passed through a maximum; the "peak". These considerations can be embedded in a causal loop diagram, as shown in the figure. This diagram omits the replenishment of the resource, which does not occur in the case of mineral resources and is zero in the case of a biological resource exploited faster than it can reform itself.

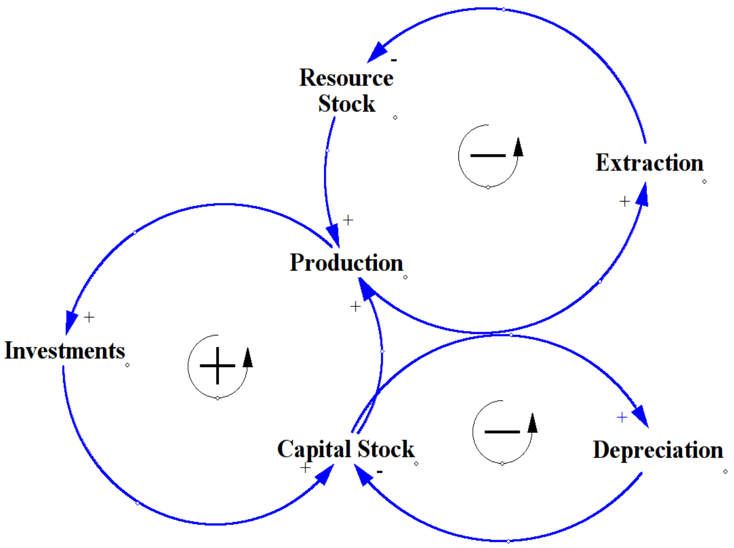

Figure 3. Causal Loop diagram of the system described in the text. Created using Vensim™. Note that in this model the resource stock is not supposed to be replenished by natural processes; that is, it is assumed to be completely non-renewable.

This qualitative description of the system doesn't tell us the shape of the production curve, for that purpose we need to perform quantitative calculations. One way is to use a simple stock and flow model, as described in detail in (Bardi 2013). Such a model is shown in fig. 4

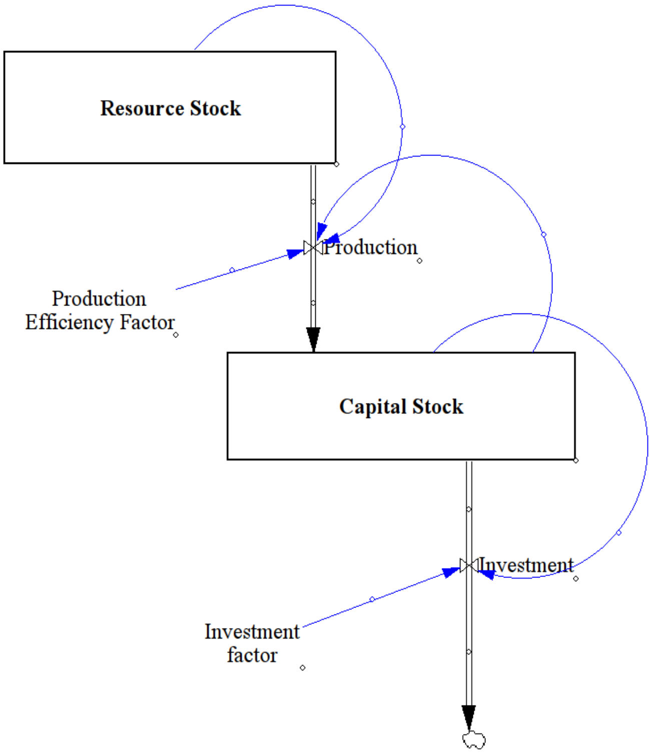

Figure 4. A simplified stock and flow model of the system described in the present paper, in the

assumption that the resource is completely non-renewable. There are other possible ways to model the system, this one emphasizes the fact that resources are transformed into capital during the exploitation process. It uses the “top-down” flow convention as described in (Bardi 2013). Created using Vensim™. The output of this model is shown in fig. 5.

It is also possible to explicit the equations that generate the model and, in the next section, it will be shown how the game engine of the “Hubbert Game” can reproduce these equations. In the hypothesis of a completely non-renewable resource, the equations can be written as (Bardi and Lavacchi 2009)

$$R' = -aRC$$
$$C' = abRC - cC$$

Here, “*R*” stands for “Resource Stocks” (e.g. crude oil) which are and transformed into the Capital Stock, “*C*” (the oil industry). R' and C' indicate the first derivative of the variable with respect to time; so that $R'$ can be understood as the *extraction* (e.g. barrels of oil per year), while C' as the *production* that builds up the capital stock. In the model, $a$, $b$, and $c$, are positive constants. “$a$” describes how fast the resource is extracted, “$b$” is an efficiency factor that describes how efficiently capital is created. If $R$ and $C$ are measured in the same units, then $b$ must be smaller than one. “$c$” describes how fast capital is dissipated. Further parameters of the model are the initial stock of resource ($R_0$) and of capital ($C_0$). Both must be larger than zero. A robust feature of the model is the generation of “bell shaped” curves for both production and capital accumulation as shown in fig 5.

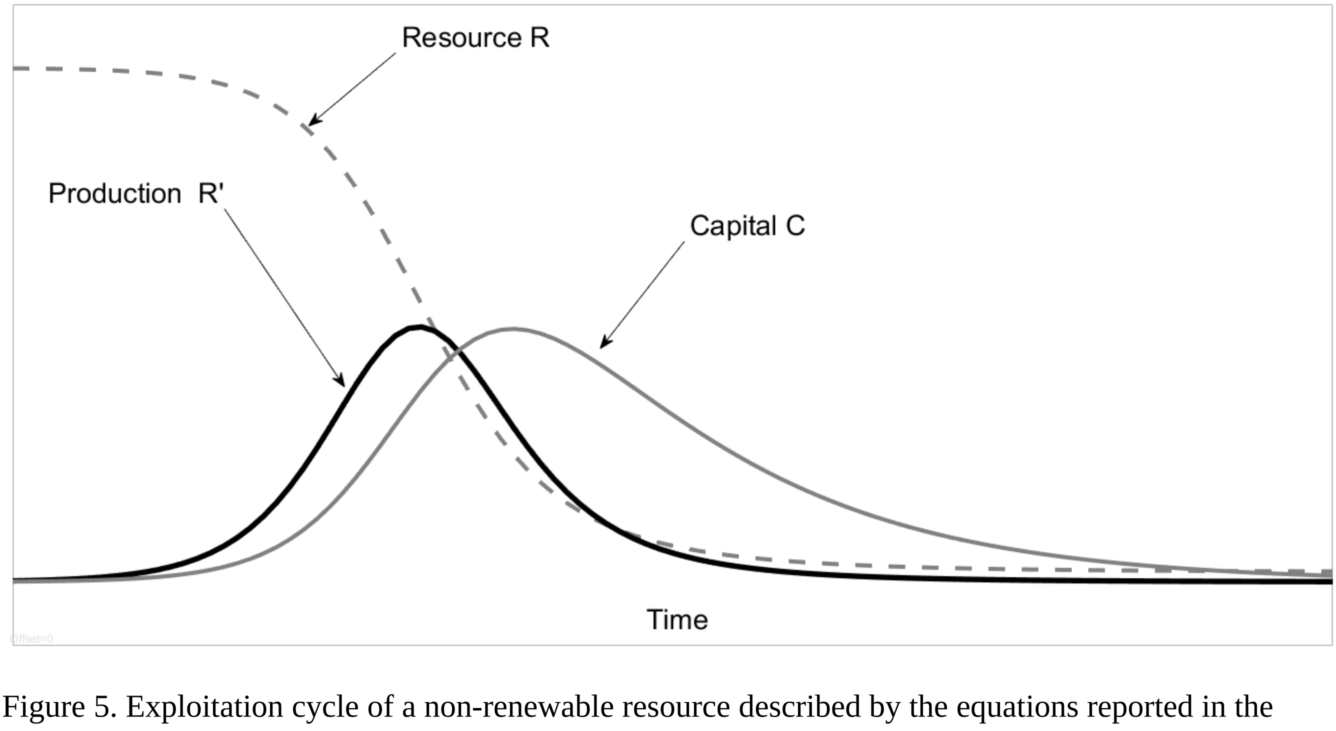

Figure 5. Exploitation cycle of a non-renewable resource described by the equations reported in the text. The production curve ($R'$) is often called the “Hubbert Curve. These curves were calculated using a Matlab routine that solves the equations described in the text, as reported in (Bardi and Lavacchi 2009).

When the resource being exploited is an energy producing resource (e.g. crude oil) a fundamental concept that affects the exploitation cycle is the “net energy” of the system, that is how much energy is actually available from the extraction, after taking into account the need to reinvest part of it in extraction facilities. This is a concept that can also be described in terms of “Energy Return of

Energy Invested” (EROI or EROEI) (Hall and Gupta 2011). EROEI is defined as the ratio of the energy obtained by a certain energy stock (e.g. crude oil) stock divided by the amount of energy needed to create and maintain the required facilities (e.g. oil drills, rigs, refineries, etc.). Obviously, a system with an EROEI smaller than one has a negative net energy and it is a net loss in terms of producing useful energy. On the contrary, a system with large EROEI is the one that generates the largest energy wealth. In the case of an energy producing resource, we may assume that the size of both stocks are measured in energy units. In this case, the instantaneous EROEI is the ratio of the energy produced ($aRC$) divided by the amount of capital dissipated to produce it, proportional to $cC$. The EROEI is then proportional to R and it goes down as the resource stock is consumed. The bell shaped curve, with its eventual productive decline, is then caused by the diminishing returns of extraction (i.e. diminishing EROEIs) (Bardi et al. 2011).

## 3. The Hubbert game

Although the model just described is rather simple, this doesn't help much the student who doesn't have the right training in solving partial derivative differential equations and not even for the causal loop or stock and flow symbols used in system dynamics. Hence, the need of a hands-on model that students can play with. The Hubbert game was built with the specific idea of creating a simple game, where the students could have full view of the “under the hood” mechanisms.

The Hubbert game engine is based on random draws from a stock of white and black counters hidden in a box (or a bag). The stock of resources is represented by the black counters, e.g. black roulette chips (black as a color appears appropriate as we are talking of crude oil as the resource). The white counters are instead assumed to be “dry holes”. Alternatively, the black counters could be described as “whales” while the white ones as “no whales”. In the course of the game, players explore for resources (crude oil or whales) by picking up a certain number of counters from the box. The extracted white counters are then placed back into the box, while the extracted black counters are defined as “discoveries” and remain in possession of the player. Each black counter in play is supposed to generate one “capital unit” that can be invested in order to explore for more resources. One capital unit is supposed to generate one investment unit that allows the extraction of a single counter from the box. This mechanism ensures a gradual depletion of the resource, which becomes more and more difficult to find as the game progresses.  The game requires also a “production sheet” on which the extracted black counters are placed, and a record sheet where players keep track of the progress of the game.

The game engine simulates all the feedback mechanisms of the mathematical description of the model. Consider the first equation: $R' = -aRC$. In the game, “$C$” (capital) is determined by the number of black counters (producing fields) that a player owns. “R” is determined by the number of black counters present in the box (undiscovered resources). Production ($R'$)  turns out to be proportional to capital times resources if we assume that, each turn, each player can perform a number of draws (explorations) proportional to the number of counters (active fields), that a player has in play. In practice, in the game we assume that each field in play produces one unit of extractive capital (one investment unit) that can be used drawing one counter from the box. Returning the white counters into the box after each draw insures that the probability of extracting a black counter diminishes linearly with the number of black counters. The game engine also accounts for the first term of the second differential equation ($abRC$), since, once discovered, resources (black counters inside the box) are transformed into capital (black counters on the game sheet). Note that we assume here that $b$ is equal to one; i.e. perfect efficiency of the extraction process. This is an obvious approximation, but it does not detract from the functioning of the game engine. Finally, the limited duration of the resources in play is simulated by having the black counters remaining a limited time in the game; that is capital is dissipated according to the second term of the second equation (*-cC*). This can be obtained by drawing a number of squares on the production sheet, arranged in a strip (a practical number of squares turns out to be four). Every turn, each team shifts right (or down) the black counters in play of one box on the sheet. The counters that leave the strip are removed from the sheet and placed nearby in the “discard pile”; they are assumed to be exhausted oil fields.

The game engine also simulates the diminishing EROEI of the extractive system. Let's say that the ratio of black to white counters in the box is equal to one (*B/W =1*), then a draw will generate 0.5 black counters on the average. Assuming that each counter stays in play for 4 turns, it generates four investments units. So, each invested unit, on the average, generates 0.5x4 = 2 investment units and, in this case, the EROEI is equal to 2. As the number of counters in the box goes down, so it does the EROEI. For instance, when the number of black counters becomes half that of the white counters (*B/W=0.5*), then the each draw will generate 0.25 black counters on the average. Then, we will EROEI= *0.25x4 = 1*. As the game progresses, lower and lower values of the EROEI stem the ability of players to grow their production base and their capital. Numerically, these EROEI values are considerably smaller than those reported for real world of oil production, which are considered to be around 20 nowadays, and much larger in the past (C. A. S. Hall, Lambert, and Balogh 2014). But these EROEI values are not unrealistic because we can assume that, in the real world, only a fraction of the total production of each field is reinvested in exploration, the rest is used to build “societal capital,” that is energy used for all purpose other than producing more energy. If we assume that about 10% of each field's production (a realistic value) is reinvested in exploration, then the values of the EROEI turn out to be qualitatively comparable to those of the real world.

This game (as all models) is obviously a drastic simplification of the real world. In particular, in the game, all oil fields are the same, produce the same, and last the same time before abruptly drying up. Nevertheless, these rough simplifications do not detract from the capability of the game of illustrating the basic features of the dynamic depletion process and the game engine generates clear “bell shaped” curves, very similar to the curve proposed by Hubbert and, in general, to those generated by the dynamic model described before for the simulation of resource overexploitation. Of course, the random element in the extraction generates a certain amount of noise, but, in general, all the practical tests showed that the bell shaped curve is a robust feature of the game output.

## 4. Testing the game

### *4.1 The simplest version*

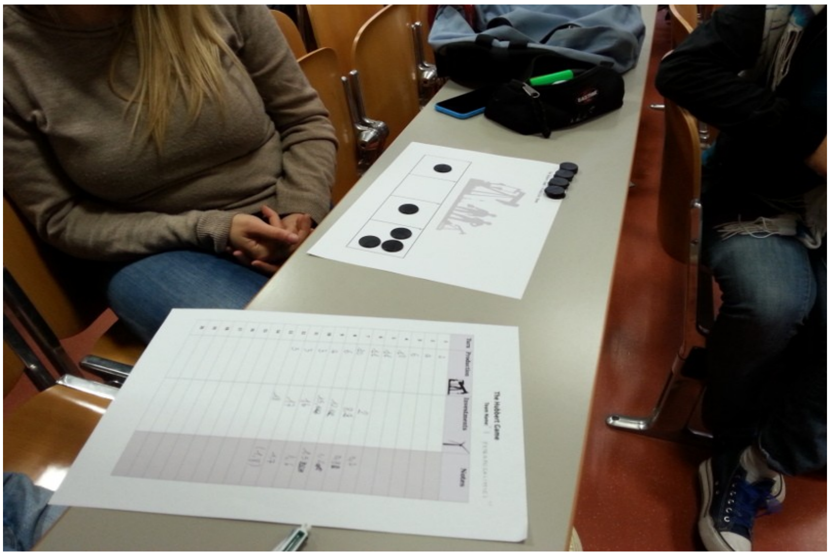

*Figure 5. The author's students engaged in playing the Hubbert game. In the image, we can see the game sheet and the record sheet*

The simplest version of the Hubbert game can be said to be competitive, but only in the sense of a game such as “snakes and ladders” is. The winner is determined by purely random factors and there is no way for players to adopt a specific strategy in order to improve their winning chances. Nevertheless, this version is valuable as an introduction. It helps players familiarize with the game and shows them how the game engine generates bell shaped curves. In this version, teams play by always investing all the produced capital to search for new fields. It is played with a single bag of counters, while players are subdivided into no more than four or five teams (players may choose names such as “Shell Oil” or “BP” or whatever strikes their fancy as the name of their team). Each turn is described as lasting five years and each black counter is supposed to be an entire oil field. The equipment needed includes some black counters and white counters, a “production sheet” with four boxes drawn on it and a “game sheet” where players record their results. The latter sheet can be simply a blank piece of paper and the game master may ask players to record such parameters as production and number of fields at each turn.

Each team starts with one producing field in square one of the game sheet (the instructor may decide to start with more than one field, this accelerates the initial phases of the game). If a team loses all its black counters during the initial phases of the game, then they restart with a single black counter in the first square of the game sheet. Being the first player each turn gives a modest advantage, so the team sequence may be randomized; although this is not strictly necessary. The game goes on in turns, with one team after the other sequentially performing the following operations:

1. Move the black counters on the production sheet of one square to the right. (in the first turn, the initial black counter is placed on the first square).
2. Discard those counters exiting the production sheet and place them in the discard pile.
3. Count the number of investment units available (equal to the number of fields in play on the production sheet)
4. Extract as many counters from the box as the number of the investment units.
5. Place the extracted black counters on the first square of the production sheet, put the white counters back in the box.
6. Record the results on the game sheet.

A manageable run of this version, that is one that doesn't last more than about one-two hours for about 10 turns, can be played with four teams, a total of 200 chips in the bag, of which about 50% are black. The strip on the production sheet is composed of four squares, that is, fields are assumed to run out after four cycles (20 years). In these conditions, the game ends, that is there are no more black counters in play, after ca. 10-15 turns. The duration of the play may also be set before it starts (e.g. ten turns). Typically, more than 4 teams slow down the game too much, whereas the duration of the game is also affected by the total number of chips. A higher black/white ratio accelerates the game. The same is true for a smaller total number of chips, but that may also increase the random noise and obscure the obtained curves. The winner is the one who has accumulated the largest capital, measured by the total number of black counters owned; obtained by summing up those present on the production sheet and in the discard pile. In this determination, it is assumed that each field that has been in play has brought a profit for the owner and that this profit is proportional to the number of fields that the team has controlled over the game.

### *4.2 Strategic versions*

There are several possibilities to modify the game in such a way to allow players to make choices that can increase their chances of winning and, at the same time, to understand other elements of the dynamics of resource exploitation. There follow some suggestions; note that not all of them were exhaustively tested, so they have to be taken as possibilities to be adapted by the instructor according to his/her needs and attitudes.

#### - *Moving to renewables (the great transition)*

This is the most thoroughly tested version of the game. It attempts to simulate how the capital accumulated by the exploitation of the oil fields can be used to build up a new energy infrastructure based on renewable energy (this transition has been quantitatively simulated by (Sgouridis et al. 2016)). In this version, renewables are represented by counters of a third color (preferably green, of course!). They can also represent nuclear plants, if liked, although in this case the green color may be inappropriate. Green counters are not subjected to depletion, nor to random factors. They can simply be bought and placed on the game sheet. Each green counter is supposed to represent a large number of renewable plants, able to produce as much energy as the number of oil fields represented by one black counter. So, each green counter is a unit of capital that generates one unit of investment, just as black counters do. To keep things simple, the game duration of a green counter is also supposed to be the same as that of a black counter, so that all counters go through the same game sheet are discarded after four turns. Green counters have the advantages over black ones that they are not subjected to random factors. However they cost more, at least at the beginning of the game. Their cost is supposed to go down as game progresses in order to simulate the effect of technological progress and of scale factors.

In practice, the game is based on a table with the cost of green counters as a function of the game turn. Initially, green counters are unavailable (not marketable on a large scale, yet). Then, they start to appear, but they are very expensive. But, as the game progresses, the cost of black counters increases, while that of green counters diminishes. Players have to balance their resources in such a way to be able to move to renewables before they run out of oil resources. A possible table that describes the declining cost of green counters is the following. Note that the breakeven point (EROEI=1) occurs at turn 5, assuming a productive duration of four turns for each counter. In the last turn, renewables are assumed to have an EROEI = 4. Again, this value indicates only the fraction of energy which is actually re-invested in new plants; each one will produce a larger amount that is assumed to be reinvested in social capital.

| Turn | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cost | x | x | 8 | 5 | 4 | 3 | 2 | 2 | 2 | 1 |
| EROI | x | x | 0.37 | 0.8 | 1 | 1.3 | 2 | 2 | 2 | 4 |

When using this table, it is advisable to reduce the number of counters in the bag, for instance halving the number to 50/50. This reduces the fossil capital available and forces the players to move faster to renewables.

#### - *Geographical choice*

This a simple strategic variant of the game. It doesn't contain elements different than the basic version, but it gives the possibility to players to take decisions that will affect the final outcome of the game. In this version, there are two (or more) bags of counters. Each bag represents a different geographical location (these different locations can be described to players with familiar names, e.g as “Middle East”, “North America”, “North Sea”, and the like.). The bags may contain different numbers or combination of black/white counters. That is, some location may be resource-poor (fewer black counters) and others may be resource-rich (more black counters). Note that the duration of the game is determined by the total number of black counters in play, that should not be much higher than about 100 in order to keep the game time within one-two hours. Players may be told or not that some regions are richer than others, but they should not be told the exact black/white counter ratio in each. They will have to decide where to employ their available investment units, taking into account the previous results of extractions that give them some information about the abundance of the resources in each areas. Of course, the areas that are discovered (or are known to be) be richer will attract more investments at the beginning, but these areas will also be depleted faster. So, the players have to balance several factors in their decision of where to employ their capital. Success should go, theoretically, to the team making the best choice in the allocation of their capital, even though random factors remain important in determining the final outcome.

- *Conventional vs. non-conventional oil fields.*

This version attempts to simulate the “switch to shale oil” that has characterized the oil industry during the past decade or so. It uses two bags of counters. One simulates “conventional” oil fields, the other “non-conventional” oil fields; the latter may be described, as, for instance, tar sands, deepwater, heavy oil, tight oil, or other. Conventional oil fields are supposed to cost less than non conventional fields, but the latter to be richer in resources. To simulate this difference, extraction from the “conventional” bag is supposed to cost one investment unit per extraction, as in the standard game. However, extraction from the “non-conventional” bag is supposed to cost twice as much; that is, players need two units of capital per counter extracted. This higher cost is compensated by a higher number of black chips in the non conventional bag. Numbers may be adjusted here; for instance the conventional bag may contain a 50/50 ratio of black to white (e.g 80 black chips and 80 white chips), whereas the non conventional bag may contain 100/50 ratio (e.g. 80 black to 40 white). Also in this case, the duration of the game is determined by the total number of black counters, so it should not be too large. In this version of the game, players are supposed to exhaust first the low cost resources (conventional ones), then to move to the more expensive ones when they have accumulated sufficient capital to be able to do so. To optimize their production, they will need to strategically balance their investments in such a way to move neither too slowly nor too fast from conventional to unconventional.

- *Other versions.*

Some versions of the game were only partially tested or were found to work poorly during the testing. The failure of these versions doesn't mean that they cannot work, just that the parameters have to be adjusted in such a way to ensure a smooth development of the game. They are reported here for completeness and for possible future development.

- *The financial exit version*. In this version, players are allowed to “invest” their capital units instead of using them to prospect for new fields. In the game, at each turn, every team may invest as many capital units as the want; marking the number on a separate sheet and receiving an interest on it. This version turned out to be complex to manage and it often happened that a team invested everything they had and then they found themselves outside the game, without anything to do.

- *The Hubbert wargame*. In this version, players can trade one investment units in exchange for “military counters” that can be used to attack other players in order to steal their oil fields. Upon testing, this version was found to be fun for the students, and perhaps even realistic when compared to what has happened (and happens) in the real world. However, it is not a way to teach to students the mechanisms of overexploitation.

- *The "fishbanks" game*. In this case, the resource is supposed to be slowly renewable; as a biological resource, e.g. a fishery. This requires the game master to keep track of the number of black counters in the game box and to add some black counters at each turn. This number can be defined, for instance, as 20% (rounded off) of the number of black counters present. In this version, players are encouraged to collaborate in such a way to attain a "sustainable" exploitation rate of the resource. This version was tested once, and it appears to be working. In practice, however, the time required to attain a sustainable exploitation rate is rather long and the game turns out to be cumbersome. It may be possible to find a combination of parameters that make this version easily playable, but that will take some more testing.

## 5. The game as a learning tool

In the testing of this game, the author found that it is essential that the students are extensively briefed before playing. This briefing involves not only a thorough explanation of the mechanisms of the overexploitation of natural resources, but also of how the game simulates these mechanisms. If the latter part is skipped, the author found that the students are not usually able to understand the connection of the game results with the historical cases of resource overexploitation they have been told about. So, the debriefing should be done according to the following steps

1. Description of the mechanisms of overexploitation of natural resources. This point is too vast to be described in detail here but, for instance, an excellent description of overexploitation can be found in the 2004 version of "The Limits to Growth" (Meadows et al. 2004). Concepts such as the Energy Return on Energy Investment (EROEI) (Murphy and Hall 2011) can also be described.

2. Showing some examples of the Hubbert curve. Two such examples can be found in the present paper as fig. 1 and fig. 2. The instructor should be careful to point out that the real world is complex and that many other historical cases do not show the same good correspondence of model an theory. In particular, the production of crude oil in the United States stopped the declining trend around 2010 and restarted to grow as the result of the industry turning to "shale oil" resources. The students should understand that models are an approximation of reality, useful for understanding the factors that lead to a certain behavior, but should be used as predictive tools only with great caution.

3. (optional) Description of the system dynamics model of the process of exploitation (and overexploitation) of natural resources. This description can start from the well known Lotka-Volterra model, or from the standard description of "stock and flow" models according to the normal conventions of system dynamics (Bardi and Lavacchi 2009). This step was found to be difficult for students whose curriculum is not oriented toward system dynamics or similar methods. Fortunately, it was also found that it can be skipped without hampering the students' capability of understanding the subject.

4. Description of how the boardgame works. The students should be told about the box with the black and white counters and explained how the gradual extraction and the non replacement of the black counters simulates depletion. The "game engine" in the form of black/white counters is normally rapidly understandable by students, especially if it is described to them in terms of simulating fishing. Describing it as simulating oil extraction, sometimes, the students may object about putting the white counters back into the box by saying, "but nobody will drill again in the same places!" A good answer to this objection is to cite the case of whaling: whales keep moving,

and therefore you can always find them in places where you already looked for them. But, of course, that doesn't apply to oil wells and the students may have in mind something like the well known “naval battle” game, where ships don't move (at least in the pencil and paper version). However, depletion occurs also in the naval battle model if we consider that the largest ships are found first. In any case, it should stressed that the game engine in the form of black and white counters is simply a way to simulate a generic situation in which the probability of finding a stock of resources is directly proportional to the amount of existing resources.

5. During the game, especially with the simplest “non strategic” version, the instructor can point out to the players how the number of black counters dwindles in the bag and how it becomes progressively more difficult to sort out black counters. The EROEI of the “extraction” may be calculated on the spot and discussed with the students.

6. Debriefing, formal or informal, can also be performed after the game with the purpose of determining whether the students understood the mechanism of depletion and how the game simulated it. Finally, they can be encouraged to plot their data by hand on a square grid. The result will normally be a well recognizable bell-shaped curve, as shown in fig. 6

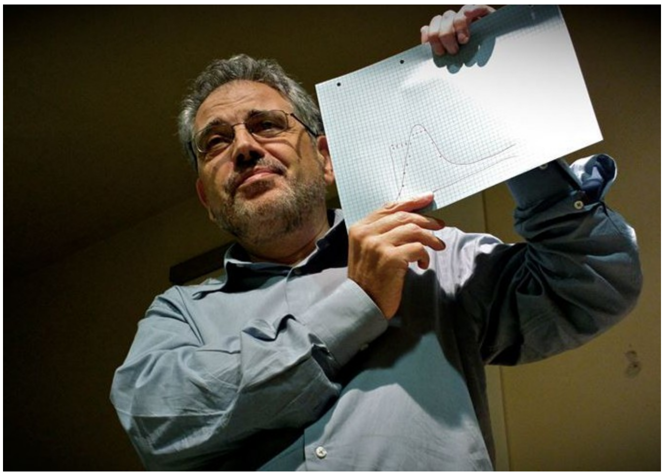

*Figure 6. The author showing the results of a run of the Hubbert game, the “bell shaped” curve, plotted by the students on a square grid paper.*

As a general observation in how to describe this game; note that it is focused on the effects of physical limitations that lead to the overexploitation of the resource being considered. However, the game is not supposed to lead the students to believe that this is the only factor affecting the exploitation of natural resources and it should be made clear to them that there are many other factors. For instance, this game may describe the overexploitation of fisheries but, in many cases, the fish stocks are affected not just by the fishing activity but also by pollution. Then the belief that technology will “change the rules of the game” is legitimate but, obviously, it can hardly be taken into account within a boardgame with fixed rules! It is up to the instructor to lead the students to understand that changes in the economic and technological background of the system do change its behavior, as it has been observed in many historical cases. As usual, the map is not the territory, but that doesn't mean that maps are useless.

## 6 - Practical considerations.

Most of the tests reported here were performed using low-cost plastics roulette chips. However, counters can be anything of the right size and easily distinguishable in terms of color and the first tests of the game were performed using door felt pads of different colors. Other kinds of informal counters could be used, for instance beer caps (Vanclay et al. 2006). Considering that we need at least 200 counters, it is a lot of beer to drink, but many students will probably be happy to help. A card deck was also tested, using the black and red cards to play the role of black/white counters. However, as the deck has to be large (typically some 200 cards) and it has to be reshuffled at each turn, handling it turns out to be cumbersome. Of course, the mechanism of extraction described here can be easily simulated on a PC, but that detracts from the idea of creating a completely hands-on boardgame. The production sheet was printed and distributed to players (it is reproduced at the end of this article). The game sheet, where players record their results, may be simply a blank sheet of paper.

The maximum number of players who participated in each test was about 20. The game was tested three times with the students of the author class on resource economics at the university of Florence, in Italy and once more with another class on the same subject given by professor Luca Pardi. It was tested once with the students of a class of Physical Chemistry, also kept by the author. Then, it was tested once at a public meeting of environmentalists and, finally, several times with some of the author's friends.

## 5. Conclusions

The operational game presented in this paper is still in a testing stage and maybe it will remain so for a long time. From the tests performed, it can be said that it surely catches the students' attention. Also, the opinion of the students about the game appears to be largely positive, although the game was not tested on a sufficiently large number of students for having a statistical significance. In this respect, the results of this testing agree with those reported about several sustainability games (Dahlin et al. 2015). However, it is not enough that student like the game and that they report of having had a positive experience in playing it. What matters is whether that improved their understanding of the matter covered by the game; in this case the dynamic factors determining the cycle of exploitation of a natural resource. As mentioned in a previous section, this is possible only if a thorough briefing of the students is performed before and during the game. Further tests of the game are in progress and, of course, this kind of testing would benefit from a larger diffusion of the game and the purpose of the present publication is to ask to other teachers to try and discuss their results. Inquiries about this game are welcome at the author's address: ugo.bardi@unifi.it

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# The Hubbert Game – Production Sheet

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Ayres R (2007) On the practical limits to substitution.

Bardi U (2013) Mind Sized World Models. Sustainability 5:896–911. doi: 10.3390/su5030896

Bardi U (2007a) Energy prices and resource depletion: lessons from the case of whaling in the nineteenth century. Energy Sources, Part B 2:297–304. doi: 10.1080/15567240600629435

Bardi U (2007b) Energy prices and resource depletion: lessons from the case of whaling in the nineteenth century. Energy Sources, Part B Econ Planning, Policy, 2:297–304.

Bardi U, Lavacchi A (2009) A simple interpretation of Hubbert's model of resource exploitation. Energies 2:646–661. doi: 10.3390/en20300646

Bardi U, Lavacchi A, Yaxley L (2011) Modelling EROEI and net energy in the exploitation of non renewable resources. Ecol Modell 223:54–58. doi: 10.1016/j.ecolmodel.2011.05.021

Bradley RL (2007) Resourceship: An Austrian theory of mineral resources. Rev Austrian Econ 20:63–90. doi: 10.1007/s11138-006-0008-7

Brandt AR (2007) Testing Hubbert. Energy Policy 35:3074–3088. doi: 10.1016/j.enpol.2006.11.004

Catton W (1982) Overshoot, the ecological basis of revolutionary change. Illinin Books Edition, Chicago, Il

Cook C, Stevenson J (1996) The Longman Handbook of Modern British History, 1714-1995. Longman, London and New York

Cronin M, Gonzalez C, Sterman J (2009) Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. Organ Behav Hum Decis Process 198:116–130. doi: 10.1016/j.obhdp.2008.03.003

Crookhall D (1990) Review of FISH BANKS, LTD. Simul Gaming An Inter-national J Theory, Des Res 21:208–211.

Dahlin J-E, Fenner R, Cruickshank H (2015) Critical evaluation of simulations and games as tools for expanding student perspectives on sustainability. In: EESD15 – The Seventh International Conference on Engineering Education for Sustainable Development, Vancouver, June 9-12.

Forrester J (1989) The beginning of system dynamics Banquet Talk at the international meeting of the System Dynamics Society. Stuttgart, Germany

Goeller H, Weinberg A (1978) Age of substitutability: what do we do when the mercury runs out. Am Econ Rev 68:1–11.

Hall C, Gupta A (2011) A Review of the Past and Current State of EROI Data. Sustainability 3:1796–1809. doi: 10.3390/su3101796

Hall CAS, Lambert JG, Balogh SB (2014) EROI of different fuels and the implications for society. Energy Policy 64:141–152. doi: 10.1016/j.enpol.2013.05.049

Hardin G (1968) The tragedy of the commons. Science (80- ) 162:1243–1248.

Hemmingsen E (2010) At the base of Hubbert's Peak: Grounding the debate on petroleum scarcity. Geoforum 41:531–540. doi: 10.1016/j.geoforum.2010.02.001

Hieber R, Hartel I (2003) Impacts of SCM order strategies evaluated by simulation-based "Beer Game" approach: The model, concept, and initial experiences. Prod Plan Control 14:122–134. doi: 10.1080/0953728031000107680

Hubbert MK (1956) Nuclear Energy and the Fossil Fuels. In: Spring Meeting of the Southern District, American Petroleum Institute, Plaza Hotel, San Antonio, Texas, March 7–8-9,. San Antonio, Texas,

Jevons WS (1866) The Coal Question, 2nd revised edition. Macmillan and Co

Kirby MW (1977) The British Coalmining Industry, 1879-1946. The Macmillan press Ltd., London and Basingstoke

Meadows D (2007) A brief and incomplete history of operational gaming in system dynamics. Syst Dyn Rev 23:199–203. doi: 10.1002/sdr.372

Meadows DH, Meadows DL, Randers J, Bherens III W (1972) The Limits to Growth. Universe Books, New York

Meadows DH, Randers J, Meadows DL (2004) Limits to Growth: the 30 year update. Chelsea Green, White River Junction

Murphy D, Hall C (2011) Energy return on investment, peak oil, and the end of economic growth.

Richardson G (2013) System dynamics. In: Encyclopedia of operations research and management …. Springer New York, New York, pp 1519–1522

Sgouridis S, Bardi U, Csala D (2016) The Sower's way. Quantifying the Narrowing Net-Energy Pathways to a Global Energy Transition.

Simon J (1981) The Ultimate Resource. Princeton University Press

Starbuck A (1989) History of the American Whale Fishery. Castle

Sterman J, Meadows DL (1985) STRATEGEM-2: A microcomputer simulation game of the kondratiev cycle. Simul Games An Int J Theory, Des Researc 16:174–202.

Sweeney L, Sterman J (2000) Bathtub dynamics: initial results of a systems thinking inventory. Syst Dyn Rev 16:249–286.

Valero A, Valero A (2014) Thanatia: the destiny of the earth's mineral resources. World Scientific Publishing Company, Singapore

Vanclay J, Keenan R, Gerrand A, Frakes I (2006) Beer-bottle tops: a simple forest management game. Int For Rev 8:432–438. doi: 10.1505/ifor.8.4.432

(2006) The Coal Authority. https://www2.groundstability.com/. Accessed 22 May 2006