Technical Innovations and Banking in a Quantum Economy

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Abstract

The economy often moves in large jumps. For example, bank runs can quickly cause an economy to suddenly drop into a deep recession. In this paper, bank approval of loans to a genius entrepreneur may cause an economy to jump to a higher income level or growth rate. In a simple model, this implies that the economy has the possibility to exist in discrete states, a ground state (lowest production level) or an excited state (higher production levels). In a more dynamic model, bank approval of the loan causes an apparent technology shock that temporarily increases economic growth. In this paper, the economy is modeled as a regime switching model, i.e. a Markov-Switching model.

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1 Introduction

How inventions have increased wealth, quality of life and life expectancy in the modern world inspired me to write this paper. Not only has technology increased longevity, but also how many people the world can support. In the modern world, in order for many inventions to increase wealth and quality of life, it must be massed produced. Mass production of new goods require investment, often funded through loans from banks. However, not all good ideas are recognized by bankers. Thus, whether an invention is ever brought to fruition often depends on the whims of a banker, much in the same way an idea for a novel depends on the whims of publishers. In this case, one fickle decision can determine whether an economic boom occurs or not. An outside observer might conclude that there were two possible equilibrium paths that the economy could have followed.

The financial collapse and subsequent great recession is another inspiration for writing this paper. In September of 2008, the collapse of Lehman Brothers caused a run on investment banks. In the next following months, much of the western world would plunge into the deepest economic downturn since the Great Depression. Many financial analysts blame the Federal Reserve and the United States government for letting Lehman Brother's collapse. Thus, one fickle decision by U.S. officials may have caused a financial panic and deep recession. From an outside observer, such decision appears random and arbitrary. He or she could reason that a decision to bail out Lehman Brother's could have prevented a financial panic and kept the ongoing recession mild. Once again, the outsider observer might conclude that there were two possible equilibrium paths the economy could have followed.

Multiple equilibria models have been used to describe why the economy can boom then suddenly collapse. In Diamond and Dybvid (1983) bank runs can occur when savers believe that the probability of a bank run is high. Thus, beliefs are self-fulfilling. Masson (1999), analyzing the phenomenon of contagion, believe that it may be useful to formulate models that do not have a unique equilibrium. Gartner and Griesbach (2012) find strong evidence of multiple equilibria and self-fulfilling prophecy in the market for sovereign bonds. Cooper and John (1988) constructed an economic game theory model with multiple equilibria. In their paper; cooperation increases economic output if there are spillover effects and strategic complementarities.

The title of this paper makes reference to the word quantum. The word quantum means a fixed discrete amount. This does not necessarily imply multiple equilibria. Rather it could mean that a unique equilibrium can only occur at fixed discrete points in a function. However, without continuity, there maybe no existence of an equilibrium. We will see that in the model described in the next section, multiple equilibria exist only if preferences are random. If preferences can be pinned down, then the model has a unique solution, but the equilibrium point can only occur at fixed discrete points. Nevertheless, in the real world, often times bankers and government officials really do decide whether to go under a big project with large economic implications or not.

The idea of multiple equilibria in economic models is unsettling to many economists. For example, Morris and Shin (2000) criticize models with multiple equilibria because they are a result of indeterminate beliefs. A shift in beliefs that causes a change from one equilibrium to another is left unexplained. Moreover, without uniqueness of an equilibrium it is difficult to perform comparative-statics analysis.

My response to the criticism is that in the real world, from an outside observer' perspective, beliefs really could be indeterminate. A small change in circumstances could have caused then Federal Reserve Chairman Ben Bernanke to change his mind of not to bailout Lehman Brothers. Nevertheless, it may be possible to assess the probability of which equilibrium will prevail, in a sense converting the multiple equilibrium model into a single equilibrium model. Nevertheless, if we could have read Ben Bernanke's mind, then beliefs are not indeterminate. However, at best we could only make an educated guess of what was on Bernanke's mind. But this could have been done with a rational procedure, where an economist attempting to make economic forecasts could have estimated the probability that Bernanke would have changed his mind not to bailout Lehman Brothers. Thus, converting the multiple equilibria problem into an unique equilibrium problem.

In this paper, economies can exist in the ground (low production) state or an excited (higher production) state. In fact, for most of human history the economy did indeed exist in or near the ground state. For thousands of years, humans had no banking system, and thus, large projects that could accelerate economic growth did not exist. In many ways, depressions caused by great financial collapses such as the Great Depression is like the economy collapsing from a higher to lower state. In the following model, approval of loans for one large project by a bank can cause an economy to make a discrete jump from the ground state to an excited state.

One objection to this approach would be that in a large economy one large project only increases economic wealth by an imperceptible amount. I disagree, a president's preference for a large public works project or for austerity can steer the economy into two different paths. Nevertheless, discrete jumps in wealth can occur if bank acts are synchronized with the acts of other banks. Therefore, a macroeconomic event shared by all banks, can cause them to take the same action at the same time. If all banks increase their lending activity at the same time, the macroeconomic economy can take a discrete jump to a higher state. Likewise, a bad economic event shared by all banks can cause the economy to make a discrete fall into a lower state, like dropping a coin into a well.

Thus, in this paper, the equilibrium state of a small town economy depends on whether the bank approves a loan for a large proposed project that will increase production of the economy. But a unique solution is possible if we can characterize what determines the probability that the bank will approve or disapprove the loan.

The outline of this paper is as follows. In section 2, I describe a two period model. In section 3, I characterize the equilibrium and extend the model to infinite periods, then draw up conclusions in section 4.

2 The Model Setup

2.1 The Village

The economy is set a long time ago in an isolated small town near the sea. The world exists for two periods and then is swallowed up by the sun when it becomes a red giant. The inhabitants use to be wandering hunter-gatherers, but because of the abundant fish in the sea and fruit growing in a nearby forest, they have decided that they can settle down and establish a small fishing village.

In the beginning of the town, people lived by collecting their own food on the beaches and in the forests. But there has been gossip that certain people have dreams to invent new ways of catching fish, growing food and hunting game. But these new projects cannot be undertaken unless these entrepreneurs can be promised the necessities of life while they build up their manufacturing enterprises and business. These rumors lead to at least one member of the village to start a bank. In the first period of the town, entrepreneurs must decide if they really want to undergo their projects and actually seek a loan from the banker. The banker must be able to collect funds to lend, and then decide which projects to fund. The banker basis his decision whether to fund the project or not on factors such as general businesses conditions, and whether the entrepreneur has good prospects of paying back the loan.

The village is called Little Town. Little Town has just been established and all of its inhabitants collect their own food to eat. The world lasts for two periods and then is swallowed up by the sun when it becomes a red giant. In period 1, Ben is a banker who dreams that people will create technologies that will allow people to consume more than their basic needs. He will have to take a survey to see if there is enough food for everyone such that there will be people who will put money in the bank. Likewise, some people aspire to be entrepreneurs that will create more wealth, but more importantly, fulfill some of their dreams of building a better world.

The condition that people must consume a minimum quantity of goods to survive is also called the minimum expenditures requirement. This minimum expenditures requirement maybe a reason why it takes a long time for poor societies to experience economic growth. For example, Chatterjee and Ravikumar (1997) concluded that because of the minimum expenditures requirement, poorer countries, must spend resources to satisfy there basic needs. Therefore, they have less resources and money left over for other types of spending such as investment spending. This causes poorer countries to experience lower growth rates.

Little known to Ben, the technology genius is a rare person. If Ben can imagine a world filled with little villages, like his own Little Town, he would observe that a technology genius is born somewhere in the world only once every few years. Furthermore, a technology genius that is willing to become an entrepreneur and sell his or her invention comes along only once a generation. If the loan for producing and marketing the invention is approved, the local economy will boom. However, bankers have difficulty recognizing such an invention. Most inventions do not increase overall economic productivity by that much. The question is whether bankers like Ben recognize when a science genius's invention is a positive technology shock that economists such as Kydland and Prescott (1982) have speculated about.

But Little Town does not exist in a New Classical world. Rather, not only does Ben wish to maximize his bank's profits, but fulfill his dreams. His dreams can lead to a socially undesirable result since his dreams may not match the dreams of society as a whole, or society may be dream neutral.

There has been arguments in the economics literature in favor of bounded rationality. Oechssler et al. (2008) finds evidence that people with low cognitive abilities tend to display more judgment bias than high cognitive people. Thus, education can reduce judgment bias in society. Stanovich (2013) finds evidence that irrationality often arises because individuals desire more than just satisfying first order desires. Finally, Barberis and Thaler (2003) argue that arbitrage not always drives an economy to efficiency, and that bounded rationality can be modeled.

2.2 Period 1

Sharon is a fairly unique person in Little Town, and is that special inventor. Unlike most people, she has a dream of not spending her life collecting food on the seashore or in the forest. She has a dream of creating new farm technologies, K (capital). If her dream is fulfilled, food production will become so great that people will have enough time and food to spend on consumption other than those that fulfill their basic needs. Right now, her budget constraint is that she either consumes, saves or invests what she earns in income:

$$A^1 f(N^1) = Y^1 = C^1 + S^1 + K^1 \tag{1}$$

where A is a productivity parameter, in this model associated with the quality of the climate, f is the production function, N is hours spent on the beach collecting food, Y is income, C is consumption, S is savings and superscript 1 denotes the first period. Note that the fruits of capital are not obtained until the second period. Sharon also faces a minimum consumption requirement in every period of:

$$C^t \geq C_s^t \tag{2}$$

where superscript t denotes period t. If the minimum requirement is not fulfilled, Sharon dies and does not survive the existing period.

Sharon also maximizes her discounted utility, which depends on her hours worked and the amount of goods she consumes in each period. However, for the purpose of this paper, I choose not to tell this part of the story. I well tell you that as a result of her utility maximization she will choose a combination of hours worked, and her total consumption for each period. I am only interested in the case where she will ask for a loan, described below.

Sharon has an alternate choice to labor. She can choose to become an entrepreneur and build a farm, but in order to do that she must obtain enough loans to satisfy her minimum consumption requirement in period 1 and a minimum requirement of funds to complete her project. Sharon must obtain loans because if she undertakes her project, she must devote all of her energies into building her farm. Because of this reality, if she chooses to become an entrepreneur she earns no income in period 1 or:

$$A^1 f(N^1) = 0 \tag{3}$$

Let K_m^1 denote the minimum expenditures or capital K^1 required to finish a product, which is usually relatively large when compared to personal income Y. Equation (2) implies that in order for Sharon to become an entrepreneur Ben must agree to give her at least enough loans D to satisfy the requirement:

$$D^1 \geq C_s^1 + K_m^1 \tag{4}$$

If Ben loans the minimum amount of funds to just barely satisfy Sharon's minimum requirement to become an entrepreneur, Sharon will have zero savings. She could have positive savings if Ben loans her more then the minimum requirement. Sharon will first determine if both alternatives satisfy her survivability requirements. If both alternatives do, she then compares which alternative maximizes her expected utility.

Ordinarily, in an economy where a banker has monopolistic powers, the banker can choose his or her own interest rates. However, I will assume that Ben is bounded by the elder council in the community that has imposed usury laws allowing the council to fix the interest rate. The interest rate is fixed below the monopolist's optimum price, but above the competitive equilibrium price. I make this assumption merely to simplify the analysis and argue that the ability to fix interests rates is not a necessary component of my story.

Ben earns profits by using bank deposits to fund projects proposed by entrepreneurs or large investors. The amount of bank deposits used to fund projects is denoted as B. In order to earn a profit, Ben must charge large investors a higher interest rate than the rate of interest he must pay his depositors. Furthermore, bank revenues $f(B)$ in nonlinear because revenues also depend on how many investors default on their loans. The usual assumption is that the following conditions hold:

$$f_1(B) > 0 \tag{5}$$

and

$$f_{11}(B) < 0 \tag{6}$$

where f_1 denotes the partial derivative with respect to B, and f_{11} represents the second partial derivative with respect to B. Equation (5) states that revenue increases with B and equation (6) assumes that the revenue function f is concave. These assumptions ensure that the maximization problem will have a unique solution under the assumption of continuity.

In a New Classical world, the Ben's objective is to maximize the bank's profits Π by choosing a level of assets it invests in projects. The amount of deposits not chosen for investment will be kept in vaults for safekeeping denoted as U. Therefore, total deposits are given by the equation:

$$D = B + U \tag{7}$$

Even if the money is not used for further investments, the bank is still important because it can keep the money safe from thieves, something that the average depositor might not be capable of doing. Let B represent bank deposits that are invested, r_B the interest rate the banker pays the depositor and L represent assets from a large investor, and r_L the interest rate it charges to fund the projects of large investors. Ben's objective can be stated as choosing $B = B^*$ such that:

$$Max\ \Pi(B) = Max\ [r_L f(B) - r_B(B+U)] \tag{8}$$

But Ben cannot collect more assets than the aggregate amount of possible surplus consumption $\sum C_s$. The possible surplus consumption is the amount of consumption over the minimum consumption requirement needed to survive. We will assume he cannot invest more than the total amount of deposits $\sum D$ in his bank, which is also less than total surplus consumption in Small Town since not all surplus consumption is deposited in the bank. Thus, Ben faces a constraint of:

$$B \leq \sum D \leq \sum C_s \tag{9}$$

If $\sum D$ is positive then the first order condition is:

$$f_1(B) = r_B/r_L \tag{10}$$

The optimal solution is to choose the amount of assets to be invested in big projects B^* where the marginal product of the assets is equal to its marginal cost. If $\sum C_s$ is not positive, then Ben will not form the bank. In fact, we can extend the model to include expectations. In a model with expectations, Ben will not form the bank unless the expected bank profits exceed what he can earn collecting food on his own.

In assessing whether to fund an individual project or not, the profit function Π will depend on the credit worthiness of the entrepreneur and project. Credit worthiness will depend on state of the climate A^1. Thus, the profit function may be written as $\Pi(A,B)$; however, A is not a choice variable. But the value of A could have large implications since a very low A could make all projects not credit worthy.

As mentioned above not only does Ben wish to maximize his bank's profits, but he also wants to maximize his dreams represented by his dream function ψ. Let d represent a scale Ben's desires and is positive for projects with subjective good characteristics and negative for projects with subjective bad characteristics; then Ben's problem is to maximize his dream function mathematically written as.

$$Max\ \psi[(d,\Pi(B)] \tag{11}$$

We assume that Ben's dreams are more fulfilled the greater d is or:

$$\psi_1 > 0 \tag{12}$$

where subscript 1 represents the partial derivative of the dream function with respect to the desirability scale d.

We also assume that Ben's dreams are more fulfilled the greater the bank's profits are:

$$\psi_2 > 0 \tag{13}$$

where subscript 2 represents the partial derivative of the dream function with respect to profits.

Ben's desires can be just about anything. He may desire that Small Town become a farming community, or a village that builds great statues for travelers to see. But for now, d represents a range a characteristics a proposed project might have. In this example, I assume that Ben can rate each project's desirability as a number.

For simplicity, let us assume that the dream function is linear and can be written in the form of:

$$\psi[d,\Pi(B)] = [r_L f(B) - r_B(B+U) + \Phi(d)] \tag{14}$$

where Φ is a concave function that increases with d. Maximizing the dream function in (14) by choosing a B^* and d^* yields the first order condition

$$f_1(B) + \Phi(d) = r_B/r_L \tag{15}$$

Therefore, the banker will not do optimal investing, if society is dream neutral. Projects with undesirable characteristics will receive below socially optimal funding, and projects with desirable characteristics will receive above socially optimal funding. Sometimes, macroeconomic conditions may make most projects either desirable or undesirable. If most projects become desirable, then a speculative bubble occurs. If most projects become undesirable, an economic crash occurs. In balance sheet recessions, see Koo (2009), high debt may increase the odds that a bank will go bankrupt. Therefore, high debt will cause banks to underfund projects if high debt is regarded by Ben as an undesirable characteristic.

Notice, that the model has a unique equilibria. The equilibrium will either occur if the loan is granted or if the loan is rejected. If Ben's preference were somewhat random, that is his preferences depended on random shocks, this indeterminacy would mean that the model has multiple equilibria. The outside observer would solve the problem by calculating the probability that Ben looks at farming in a positive light.

2.3 Period 2

In an economy with just Sharon as an investor, two possible outcomes are possible. If Ben decided not to give Sharon the minimum required loans, then Sharon lives her life as a collector of food in the forest and seashore. Her second period budget constraint becomes:

$$A^2 f(N^2) = Y^2 = C^2 - (1 + r^B)S^1 \tag{16}$$

Because the world is now going to be destroyed by the sun at the end of this period, there is no investment and savings in period 2. Rather, Sharon will consume all of her income she earns in period 2 and whatever she saved in period 1 plus the interest she earned by depositing her savings in Ben's bank.

But there is a second possibility where she was able to receive a loan and invest in capital equipment and extra labor. Sharon added many workers, and together they were able to produce more income than what every one could have produced separately. Thus Sharon's budget constraint in period 2 was:

$$A^2 f(N^2, K^1) = Y^2 = C^2 - (1 + r^B)S^1 + (1 + r_L)D^1 \tag{17}$$

Although Sharon must now pay back the loans she obtained from Ben in period 1 plus the interest on the loan, her income was much higher than what she would have been had she just been a collector of food on the seashore and in the forest. However, there was a chance that her project would fail. In this case, her second period income was low, and she could not pay back the loans. That is why Ben might have denied her the loans in the first place. Nevertheless, most likely the loan would have brought the economy to an excited state.

3 Equilibrium

3.1 Ground and Excited States

In the above example, there was only one entrepreneur. The fate of this entrepreneur made a large impact of the fate of the Little Town economy. Because the large proposed project was a take it or leave it deal, the economy was either going to settle on the excited state or ground state. Let Y_2 equal aggregate income in period 2, Y_1 period 1 aggregate income, the solution of the model takes the form of:

$$Y_2 = \alpha S + \beta Y_1 + \varepsilon \tag{18}$$

where S a random variable that equals zero or one and its value does not depend on the initial state of period 1, α a constant, $\beta \leq 1$ a constant assumed to be close to one, and ε an error term with mean zero and variance σ_ε^2.

The random variable S determines whether the economy will be in the ground state or excited state. If $S = 0$, the economy is in the ground state, else if $S = 1$ the economy will be in the excited state. However, in order to find the solution, a probabilistic model of which state the economy will be in must be constructed.

The characteristics of this solution occur because the project is considered to be indivisible. In most macroeconomic models, all variables are usually assumed to be divisible. This means that a variable can take on any arbitrary number, whether it is a whole number or fraction. This assumption is unrealistic for it means that

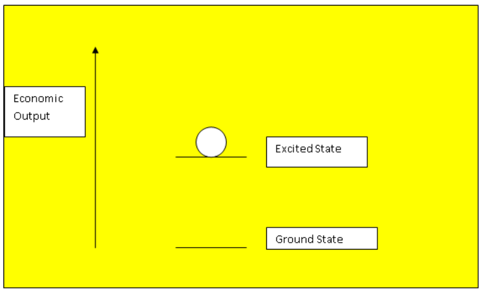

Figure 1: A ball represents the position of the economy. Because Ben gave Sharon a loan, the ball moved up to an excited state. Because Sharon's project was for all practical purposes a take it or leave deal, the local or neighborhood small economy was going to either going to settle on the ground state or excited state. This quantum story is less convincing for a large economy. However, if banks experience the same macroeconomic shocks, the economy could theoretically experience only a few discrete possible long run economic growth rates, rather than a continuum of growth rates.

people could live in an arbitrary small house. Most likely, a person can only live in a house with a minimum required size. Certainly, a house must be at least as large as the person residing in the house.

The invisibility of goods and capital goods is common in economics, especially for expensive goods such as health care insurance. For any given person, he or she has a discrete number health care plans to choose from. The cheapest plan cannot have a value or price arbitrary close to zero. Rather, there is a minimum premium each person must pay for insurance. This model could be relevant for macroeconomic models where big projects or policy changes are either approved by congress or not. For example, either a major public works project is approved by congress/parliament or not.

This economic story in this paper is very simple. An extension of this model could be to add an additional period. In period 2, banks could use the deposits they collected and invest them in the stock market or buy subprime mortgages. As we mentioned, if a common macroeconomic event occurs that causes certain project characteristics to be more desirable, then a speculative bubble could result. Once the bubble bursts, banks will fail and bank runs can occur. A bank run could occur if savings in banks depend on the perceived probability that the bank will fail. If bank failure is perceived to be likely, a large number of people will pull out their savings from banks. The above extension can then be modified to include an infinite number of periods, which we will investigate in section 3.3.

3.2 Which State?

One problem with this simple model is that it is filled with discontinuities. If we assume the case where Ben's dream function is indeterminate, discontinuities are eliminated by using probability density functions which transforms the problem into one of probability. Thus, we do not solve which state the ball is in, but rather the probability that the ball is in a certain state. Therefore, the proper way to model the above story is to transform it into one of probability where the solution will be in terms of the probability that the economy will be in the ground state or in the excited state.

The model predicts that the set of possible equilibrium solutions is discrete and not continuous. By changing the model to one that is statistical in nature, the set of possible equilibrium solutions becomes continuous. Lets modify the model and suppose the solution as an extra equilibrium, say one ground state and two excited states. The economy can exist out of equilibrium when a shock occurs that pushes the economy from one state to another. What we can do is postulate a probability density function, which will describe the relatively likelihood that the economy will exist at a given GDP level as depicted in Figure 2. In this model, to make a solution attainable, we assume that the equilibrium states are shaped like small boxes with a height of l.

We may interpret the below illustration as three equilibrium states of the economy, or where S can be equal to three discrete values. The ground state occurs when there is no banking system or a depressed banking system that has suffered massive bank runs. The middle state is located where the economy experiences normal growth, while the upper excited state occurs when the economy experiences high wealth and high growth because Ben approved the loan. The curves represent probability density function denoted as $\Psi^2(x)$ where x represents GDP output. I assume that GDP must always be greater or equal to zero.

Let A be the point corresponding to the bottom of the middle box and B the top of the box, where $A + B = l$. The probability π that the economy will reside in the lower excited state is expressed as the definite integral:

$$\pi = \int_A^B \Psi^2(x)\, dx \tag{19}$$

Because probabilities must be between zero and one, we have the requirement:

$$\int_0^\infty \Psi^2(x)\, dx = 1 \tag{20}$$

When equation (19) satisfies equation (20), Ψ is said to be normalized.

The function Ψ is complex, and depends on how each stable region is characterized and the adjustment process from one stable region to another stable region. In a multiple equilibrium model under the assumption of efficient markets, the stable regions would be the only possible equilibrium intervals.

An analogy to the illustration in Figure 2 is to think of the white ball as a ping pong ball rolling along a narrow shelf. The rectangular boxes represent dents in the

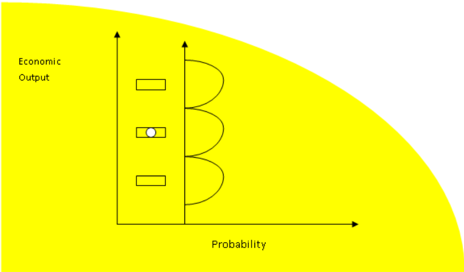

Figure 2: Three possible states depicted as triangular boxes with a height of l are depicted. The bottom box represents the ground state and the two upper boxes are excited states. The curves represent the probability density function of where the economy (the white ball) will reside. In this illustration, the economy resides in the middle state or lower excited state. Because the boxes represent stable equilibrium intervals, there is a greater probability that the economy will reside in one of the boxes. In fact, in a perfect competitive economy, where markets adjust instantaneously, the probability that the economy will reside outside of the boxes is zero. However, if adjustment is slow, there will be a positive probability that the economy will reside outside of the boxes. In models with multiple equilibria, the boxes can represent the possible multiple equilibrium boxes.

shelf with a length l and width equal to the width of the shelf. When the ball rolls into the dent, it enters a region of stability. When the dent has infinite depth, we say that the dent becomes a box. Thus, the rectangular boxes in the above figure really are not boxes but rectangular shaped narrow dents on a shelf. In order for the ball to roll to another stable dent, some force or in this case an economic shock must hit the ball. The shock may be of any kind, including changes in government policy. If the table is bounded with a wall so that the ball cannot roll off the table, and there is no friction, the ball is unstable until it rolls into one of the three dents. Certain dents may be deeper than other dents or the shelf may have a slope, making one dent more likely to be the final resting point of the ball. Therefore, in a bank run model, the economy may reside in an intermediate excited state or equilibrium the majority of the time. Bank run equilibrium may occur, but will be less frequent.

Of course, characterizing the probability density function is problematic. The only way to characterize such a function is for an economist to travel to many villages and to observe the probabilities that such projects under certain economic conditions will be approved. Either that, the economist has to discover something about the banker's dreams. Thus, the form of the probability density function is only discovered by empirical analysis.

3.3 Infinite Periods - Markov Switching Model

The model is now modified to include an infinite number of periods. In each period a genius entrepreneur asks the bank for a loan. If the bank approves the loan, the entrepreneur will build new technologies that increase output of the economy. Many entrepreneurs ask the bank for loans, but the banker cannot ex ante identify which entrepreneur is the genius. From an econometric point of view, output is now a non-stationary process because technological changes permanently increases it. Therefore, we would like to rewrite output in terms of income growth.

Moreover, at any given period t we now know what state the economy is in. The question is whether the banker will approve the loan and cause the economy to switch to a higher state, in this case, a higher growth rate state. Such models are called Markov Switching Models and were initially analyzed by Lindgren (1978). See also Hamilton (2008) for a simple explanation of switching models.

The solution of the model takes the form of:

$$\gamma_t = \alpha_0 + \alpha_1 s_t + \beta_1 \gamma_{t-1} + \varepsilon_t \tag{21}$$

where γ_t is the current economic growth rate, γ_{t-1} is the economic growth rate of the previous period, α_0, α_1, and β_1 are constants, $s_t = 0, 1$ are Markov state variables, and ε_t are independent, identically distributively (i.i.d.) random variables with mean zero and variance σ_ε^2. Notice that in order to sustain a higher growth rate, the banker must throughout time approve loans to a genius entrepreneur.

In other words, technical progress must be made in every period. If technology progress is not made in a period, then economic growth will be lower in the next period. However, economic output will still be higher because technical innovations increases the level of economic output.

The Markov state variable s_t is a random variable that switches from zero to one. When it is zero, the economy follows the lower state economic growth rate. When s_t is one, the economic growth follows the higher state, the faster economic growth rate. To complete the description of the model, requires a probabilistic model of why s_t changes from zero to one. Many models are possible. But a common specification is that s_t follows a Markov chain.

4 Conclusions

Economists has long theorized that technical progress is key to long term economic growth. For example, Solow (1957) proposed that a technical change index $A(t)$ augments the production function. In this paper, production of a new type of productive capital raises the economy from a lower to higher economic growth rate. However, in order for this new technology to be produced, a banker must approve a loan to the entrepreneur who proposes to produce the capital good. If the banker approves the loan, then what could be regarded as a positive technology shock can occur.

Although macroeconomists will be unsettled that random chance determines which equilibrium the economy will follow, this model can explain why the economy can suddenly take off or stall. If bank lending drops suddenly, then the economy can even collapse because of a financial panic. If the example is converted to a multiple equilibria model, unlike past multiple equilibria models, I have made an attempt to characterize which equilibrium will be chosen. Intuitively, one cannot say that financial panics and economic recessions of the past were pre-determined. In the case of the financial crisis of 2008, one can see that initially bankers were inspired to give out subprime mortgage loans at a rate greater than the socially optimal rate. These subprime mortgages were toxic assets. When the real estate market burst, projects became more undesirable such that loan standards increased across the board. The standards became so stringent that banks have been willing to sit on most of the cash they hold as deposits rather than give loans to entrepreneurs. This has caused the economy to drop from one excited state to a lower excited state. Should the banking industry completely collapse, the economy could drop to the ground state.

In this paper, I do not attempt to explain negative technology shocks. Rather, technical progress always increase income levels. However, failure to approve loans can cause economic growth to slow. An extension of this model is to include a financial panic state. In order to predict when big swings in the economy such as a financial panic or bank run will occur, the big challenge is to model a probability distribution of whether an event will occur. Because financial panics are rare events, this will require data that possibly go back centuries.

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