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The Uncertainty Trap: Effectiveness of macroeconomic policy [*]

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Abstract

In this paper, we explore the effectiveness of macroeconomic policy. To achieve this goal, we first discuss the theoretical framework of macroeconomics in Section 2. We explain why the standard microeconomic foundations of macroeconomics are mistaken and argue that Keynesian economics or what Tobin (1993) called the Old Keynesian view, according to which *real aggregate demand* determines aggregate production, can best explain the actual macroeconomy. We then briefly explain the microeconomic foundation of Keynes' principle of effective demand based on methods used in statistical physics in Section 3. Using this model, we explore the effectiveness of macroeconomic policy in Section 4. In the model, the difference between micro demand shocks and macro demand shocks is significant. Individual micro demand shocks cannot be observed. In fact, only the aggregate fluctuations caused by such unobservable micro shocks are observed. This is analogous to the observation of thermal fluctuations governed by temperature in physics. By contrast, macro demand shocks are observable in various forms, one of which is macroeconomic policy such as fiscal/monetary policy. We demonstrate that macroeconomic policy becomes ineffective with very low levels of aggregate demand. This result holds true irrespective of macroeconomic model specifics and is generic. Section 5 provides concluding remarks.

Keywords: Macroeconomic Policy, Uncertainty, Effectiveness
JEL classification: E00, E60

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Introduction

Standard macroeconomic policy such as fiscal and monetary policy is expected to alleviate fluctuations of the macroeconomy. However, effectiveness of such policy depends on time and place. A case in point is the long stagnation of the Japanese economy beginning the burst of stock/land price bubbles during the 1990's. A pile of fiscal stimuli and unconventional monetary policy such as zero interest rate and unprecedented quantitative easing virtually failed to revive the economy for long period of time. "Secular stagnation" of the U.S. economy after the Great Recession following the 2008-09 financial crisis is another example (Summers (2014,15)).

Obviously, it is extremely important to understand why effectiveness of macroeconomic policy was so weakened. We argue that standard micro-founded macroeconomics is inadequate to answer this question. The reason is that the essential point of this problem is not taken into account in standard micro-founded macroeconomic models.

Macroeconomics was once synonymous with Keynesian economics. However, for the last fifty years, macroeconomics has turned into neoclassical theory. The claim is that Keynesian economics is devoid of microeconomic foundations, and that correct macroeconomics must have rigorous microeconomic foundations. The "rational expectations revolution" of Lucas (1972, 73) and the real business cycle theory (RBC) of Kydland and Prescott (1982) literally transformed macroeconomics. It suffices to cite Lucas' (1987) "Declaration of Victory" as representative of the trends in the academic world.

> The most interesting recent developments in macroeconomic theory seem to me describable as the reincorporation of aggregative problems such as inflation and the business cycle within the general framework of 'microeconomic' theory. If these developments succeed, the term 'macroeconomic' will simply disappear from use and the modifier 'micro' will become superfluous. We will simply speak, as did Smith, Ricardo, Marshall and Walras, of economic theory. If we are honest, we will have to face the fact that at any given time there will be phenomena that are well-understood from the point of view of the economic theory we have, and other phenomena that are not. We will be tempted, I am sure, to relieve the discomfort induced by discrepancies between theory and facts by saying that the ill-understood facts are the province of some other, different kind of economic theory. Keynesian 'macroeconomics' was, I think, a surrender (under great duress) to this temptation (Lucas 1987, 107-108).

As Lucas suggests, since the 1980s, macroeconomics has been transformed into micro-founded macroeconomics with micro-optimization at its core. "Progress" in this research program since then is reviewed by Sargent (2025).

However, economics must be dual consisting of two pillars, macroeconomics and microeconomics. The reason is that there are two different kinds of problems in the economy. On one hand, we have micro problems such as industrial organization and market for "lemon", and on the other, macro problems such as business cycles. The essential difference between the two is that in the former, namely in microeconomics, we must explore economic motives and strategic behavior of consumer and firm, whereas in macroeconomics, detailed analysis of micro behavior is of no use. Macroeconomics and microeconomics are fundamentally different.

In this paper, we explore the effectiveness of macroeconomic policy. To this goal, we first discuss the theoretical framework of macroeconomics in Section 2. We explain why standard microeconomic foundations of macroeconomics are wrong, and argue that Keynesian economics or what Tobin (1993) called the Old Keynesian view according to which *real aggregate demand* determines aggregate production can best explain the actual macroeconomy in the short-run. We then briefly explain microeconomic foundation of Keynes' principle of effective demand based upon methods of statistical physics in Section 3.

In this model, we explore the effectiveness of macroeconomic policy in Section 4. In the model, the difference between micro demand shocks and macro demand shocks is very important. We can never observe individual micro demand shocks, but only know the aggregate level of such unobservable micro shocks. It corresponds to thermal fluctuations governed by *temperature* in physics. By contrast, macro demand shocks are observable a part of which is macroeconomic policy such as fiscal/monetary policy. We demonstrate that macroeconomic policy becomes ineffective when the aggregate level of unobservable micro shocks is very low. This result holds true irrespective of details of macroeconomic model and is generic. Section 5 offers concluding remarks.

1. Standard Micro-founded Macroeconomics

To study effectiveness of macroeconomic policy, we must fix theoretical model. In this section, we argue that standard micro-founded models are all in fatal flow for studying the macroeconomy. They are all built on detailed analyses of optimization, but optimization of micro economic agent is so diverse that it must be taken as random for the purpose of macroeconomics. By introducing such unobservable micro-optimization into model, modern micro-founded macroeconomics must rest necessarily on representative agent assumptions. In the case of real business cycle (RBC) theory and endogenous growth theory, this is obvious because literally single representative household/firm is assumed.

In contract, in the case of Lucas' rational expectations model, labor search theory, and more recent dynamic stochastic general equilibrium (DSGE) model, the problem is much subtler because in these models, apparently heterogenous agents are assumed. However, economic agents' behavior or optimization is basically the same, and they differ only to the extent that realization of relevant stochastic variable is different. They are assumed to face a common stochastic distribution with which they optimize. We contend that the assumption that all the economic agents share a common stochastic environment, namely the assumption of representative stochastic constraints is wrong. It is essentially nothing but stochastic version of representative agent assumption, not worthy of micro-foundations

(Yoshikawa (2022), Yoshikawa and Arata (2023)). Before we explain the Keynesian model based on statistical physics, we briefly comment on representative macroeconomic models.

RBC

A prototype of micro-founded macroeconomics is real business cycle (RBC) models originated by Kydland and Prescott (1982).[1] RBC is now the basic framework of standard macroeconomics. In the model, the representative Ramsey-type consumer maximizes intertemporal utility under the constraint on production which is subject to stochastic productivity shocks. Here, *macro* productivity shocks produce fluctuations of *aggregate* production or GDP.

The problem is the assumption of representative consumer. It is certainly a big embarrassment to hold that the macroeconomy is characterized by behavior of a single representative consumer because we know that consumers and firms all differ in many respects. A well-known criticism is Kirman (1992) entitled "Whom or what does the representative individual represent?" Deaton (1992) and Solow (2004) are another. The same problem applies to most models of endogenous growth which assume representative agents.

Kiyotaki (2011) argues, however, that despite of apparent set up of basic models, RBC actually does not rest on the assumption of representative consumer/firm.

> Note that the representative household is not an assumption; it arises as an implication of constant Negishi weights under complete markets as in Negishi (1960). The aggregate production function is also constructed under the assumption that production is efficient in competitive markets without friction. Therefore, the real business cycle theory does not blindly abstract from firm and household heterogeneity. By assuming that markets are functioning "well," we reduce an otherwise general model to one of the representative agent with an aggregate production function and analyze the business cycle phenomenon in this simplified economy (Kiyotaki, 2011, 197).

Negishi (1960) shows that the general equilibrium of the economy consisting of many heterogeneous consumers and firms is equivalent to the outcome of maximization of utility by the single representative consumer. In other words, Negishi proves the existence of a unique social welfare function maximization of which coincides with the Walrasian general equilibrium (GE). Drawing on this result, Kiyotaki argues that criticizing RBC for apparent representative agent assumptions is beside the mark.

First, Negishi assumes complete markets. Presence of any kind of market failures negates his results. Therefore, well-cited Kiyotaki/Moore (1997) which assumes representative consumer in the economy with market imperfection cannot legitimately draw on Negishi for justifying representative agent assumptions.

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1 The first micro-founded macro model is arguably Uzawa (1969).

Kydland/Prescott (1982) RBC is based on complete markets, and therefore, the Negishi proposition applies. However, what makes RBC a *macro* model is not the Negishi proposition, but very restrictive assumptions on utility and production functions. After all, RBC assures that utility and production functions are the same for all the consumers and firms in GE. This assumption ensures that positive (negative) *aggregate* productivity shocks raise (lower) *aggregate* production or GDP. It is extremely important to recognize that Negishi (1960)'s demonstration of the existence of social welfare function in Walrasian GE does not by itself lead us to any prediction for a particular direction of change of *macro* variables in response to a change of certain *macro* variable in the economy.[2] The Negishi proposition concerns the well-known fundamental theorem of welfare economics, and by itself has nothing to do with what makes RBC a workable *macro* model. RBC and endogenous growth models rely crucially on representative agent assumptions. After all, we can simply judge by their appearances!

Lucas/Sargent Rational Expectations Models

Lucas/Sargent Rational Expectations (RE) models are different from RBC in that consumers and producers have different utility and production functions. On the surface, there is no representative economic agent. However, all the micro economic agents are assumed to share the same stochastic *macro* model as the constraint under which they optimize. This assumption of *representative stochastic constraints* makes RE models a workable macro model. In this framework, unanticipated changes of money stock produce fluctuations of aggregate production or GDP.

The model is nothing but a stochastic version of representative agent model. This theoretical framework was first introduced by Phelps (1970). He uses a famous model of "islands" in which symmetric economic agents face the identical distribution of stochastic variables. The Lucas RE is just an example. No wonder, after 55 years, Phelps' model of islands is celebrated by proponent of this approach (Sargent (2025)).

As Aoki and Yoshikawa (2007) explain, it essentially corresponds to Markov model with symmetric one-level tree of the transition probability (Figure 1(a)). However, in reality, firms' economic environment or constraints under which they optimize are not symmetric, but all differ. In terms of Markov model, transition rates are not symmetric one-level tree, but multi-level asymmetric tree (Figure 1(b)).

[2] The problem has been actually long recognized in the field of traditional Walrasian GE. Beginning with Sonnenschein (1972), theorists such as Debreu (1974), Hildenbrand (1983), and Jerison (1999) have shown that the "law of demand" —— macro relationship —— does not ensue merely from standard assumptions in GE. Ambiguity arises from income effects when price changes. To obtain the macro "law of demand" equivalent to negative definiteness of the Jacobian matrix of price derivatives of mean demand, we must make additional restrictive assumptions such as the identical consumer preferences.

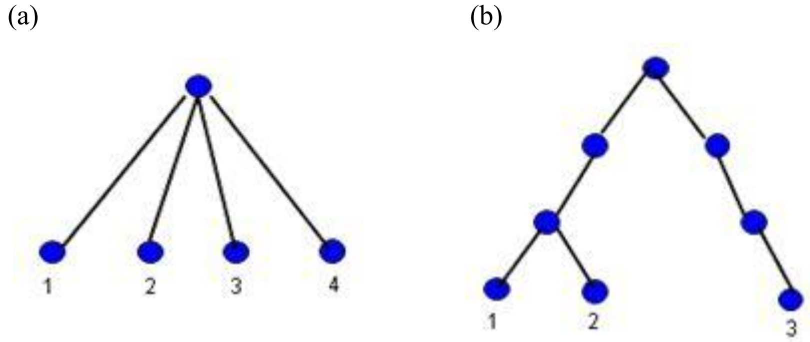

Figure 1: Tree of the transition probability of the Markov model
The figures are taken from Yoshikawa (2022).

Labor Search Theory

Search theory starts with the presence of various frictions and accompanying matching costs in market transactions. Once we recognize these problems, we are led to heterogeneity of economic agents and multiple outcomes in equilibrium. In search equilibrium, potentially similar workers and firms experience different economic outcomes. For example, some workers are employed, while others are unemployed, if they are practically similar workers. In this way, search theory well recognizes and even emphasizes the heterogeneity of workers and firms.

Despite this recognition in regard to modeling the behavior of economic agents such as workers and firms, standard search theory makes untenable assumptions. First, in the name of Poisson productivity shocks, it presumes perfect competition, namely horizontal individual demand curve in product market. It is plainly against the spirit of search theory.

Moreover, the standard model, in effect, presumes representative agent in the sense that a stochastic economic environment is common to all agents; Workers and firms differ only in terms of the realizations of stochastic variables of interest whose probability distribution is common. Specifically, it is routinely assumed that the job arrival rate, the job separation rate, and probability distributions of wages and productivity are common to all workers and firms. The job separation includes layoffs as well as voluntary quits. It makes no sense that all firms and workers face the same job separation rate, particularly the probability of layoffs. White collar and blue-collar workers face different risks of layoff. Everybody knows the difference between new expanding industry and old declining industry. Thus, the probability is far from being common to all firms and workers but is *firm-specific* and *worker specific*. Like Lucas' RE model, search model is essentially Phelps' island model.

The problem is actually partly recognized by search theorists themselves. The recognition has led them to introduce the "matching function" into the analysis. The matching function relates the rate of meetings of job seekers and firms to the numbers of the unemployed and job vacancies. The idea behind it is explained by Pissarides (2011) as follows.

> Although there were many attempts to derive an equilibrium wage distribution for markets with search frictions, I took a different approach to labor market equilibrium that could be

> better described by the term “matching”. The idea is that the job search underlying unemployment in the official definitions is not about looking for a good wage, but about looking for a good job match. Moreover, it is not only the worker who is concerned to find a good match, with the firm passively prepared to hire anyone who accepts its wage offer, but the firm is also as concerned with locating a good match before hiring someone.
>
> The foundation for this idea is that each worker has many distinct features, which make her suitable for different kinds of jobs. Job requirements vary across firms too, and employers are not indifferent about the type of worker that they hire, whatever the wage. The process of matching workers to jobs takes time, irrespective of the wage offered by each job. A process whereby both workers and firms search for each other and jointly either accept or reject the match seemed to be closer to reality.
>
> …… It allowed one to study equilibrium models that could incorporate real-world features like differences across workers and jobs, and differences in the institutional structure of labor markets.
>
> The step from a theory of search based on the acceptance of a wage offer to one based on a good match is small but has far-reaching implications for the modeling of the labor market. The reason is that in the case of searching for a good match we can bring in the matching function as a description of the choices available to the worker. The matching function captures many features of frictions in labor markets that are not made explicit. It is a black box, as Barbara Petrongolo and I called it in our 2001 survey, in the same sense that the production function is a black box of technology (Pissarides 2011, 1093-1094).

What a job seeker is looking for is not simply a good wage but a good job offer that cannot be uniquely defined but differs significantly across workers. True heterogeneity is simply unspecifiable. Pissarides recognizes such “real-world features” as differences across workers and jobs; the “universe” differs across workers and firms. Thus, he advances the idea of a macro black box. The matching function is certainly a black box not explicitly derived from micro-optimization exercises and is, in fact, not a function of any economic variable that directly affects the decisions of individual workers and firms.

Good in spirit, but the matching function is still only a half way. It is based on a kind of common sense in that the number of job matches increases when there are a greater number of both job seekers and vacancies. However, it still abstracts itself from an important aspect of reality. As Okun (1973) emphasizes, the problem of unemployment cannot be reduced only to numbers.

> The evidence presented above confirms that a high-pressure economy generates not only more jobs than does a slack economy, but also a different pattern of employment. It suggests that, in a weak labor market, a poor job is often the best job available, superior at least to the alternative of no job. A high-pressure economy provides people with a chance to climb ladders to better jobs.

> The industry shifts are only one dimension of ladder climbing. Increased upward movements within firms and within industries, and greater geographical flows from lower-income to higher-income regions, are also likely to be significant (Okun 1973, 234-235).

Unemployment cannot be separated from the qualities of jobs. The aggregate matching function still abstracts itself from true heterogeneity of workers and jobs. In considering the problems Pissarides (2011) raised, we face greater complexity and, therefore, need a “greater macro black box” than the standard matching function. Our model based on methods of statistical physics demonstrates that the aggregate matching function is actually not a structurally given function or technology, but depends crucially on the level of aggregate demand.

New Keynesian Dynamic Stochastic General Equilibrium (DSGE) Model

DSGE is a broad concept. By definition, RBC is a kind of DSGE. Here, we discuss a branch of DSGE which a group of economists call new Keynesian model.

> In August 2007, when the first signs emerged of what would come to be the most damaging global financial crisis since the Great Depression, the New Keynesian paradigm was dominant in macroeconomics. It was taught in economics programs all over the world as the framework of reference for understanding fluctuations in economic activity and inflation and their relation to monetary and fiscal policies. It was widely adopted by researchers as a baseline model that could be used flexibly to analyze a variety of macroeconomic phenomena. The New Keynesian model was also at the core of the medium-scale, dynamic stochastic general equilibrium (DSGE) models developed and used by central banks and policy institutions throughout the world (Gali (2018), p.87).

The framework is based on standard optimization of households and firms solved under the assumption of rational expectations, but unlike RBC, introduces nominal rigidities of prices and wages. Thus, it is not neoclassical economics, but allegedly Keynesian.

The first generation of new Keynesian model is representative agent model. Therefore, criticism of RBC applies to it. To the extent that such model is used for guiding monetary policy, the serious problem arises. Namely, as Kaplan, Moll and Violante (2018) show, in representative agent model, transmission from changes in interest rates to consumption is driven by intertemporal substitution of represent consumer. This is not borne out by well-known fact that the direct impact of changes in interest rates on consumption/saving is small.

This problem motivates economists to introduce *heterogeneous* economic agents into DSGE. Such model is now called heterogenous agent new Keynesian model (HANK) as compared to representative agent new Keynesian model (RANK). Does HANK such as Kaplan, Moll, and Violante (2018) succeed in introducing heterogenous economic agents? Does it provide us with useful guidance on monetary policy? Unfortunately, the answer is no.

Certainly, the direct impact of changes in interest rates on consumption/saving is small. Plainly, RANK which relies overwhelmingly on intertemporal substitution of representative consumer for the transmission mechanism of monetary policy cannot stand use. This motivates Kaplan, Moll and Violante to introduce heterogeneous agents into new Keynesian model. However, in their model, consumers are "heterogenous" to the extent that they face "idiosyncratic labor productivity shocks" which are assumed to cancel out leaving market wage unaffected.

Production of final goods is done by a competitive representative firm using a continuum of intermediate inputs. Producers of intermediate goods are monopolistically competitive. Because they are symmetric, cost minimization implies that the marginal cost is common across all producers. This analysis leads us to the New Keynesian Phillips curve. Monetary policy concerns price or inflation, of course. Their Phillips curve depends wholly on representative firm assumption, not heterogeneous agents at all. Household's income depends on wage income. Now, labor is demanded by symmetric firm, again not heterogenous at all. On the contrary to the authors' claim, the model is essentially representative agent model, not worthy of heterogeneous agent model.

In such a model, they consider the effects of a change in the short-term nominal interest rate. Such an exercise misses an essential part of monetary policy because interest rate is not all that matters. The transmission mechanism of monetary policy is explained by Tobin (1978) in plain words:

> Many businesses, like many households, are liquidity-constrained. The pace of their real investment, whether in working capital or fixed capital, is limited by their cash flow and the credit they can obtain. …… A "credit crunch" is not just a time of high and rising interest rates. It is a time when some business customers of commercial banks find that they cannot fully use the credit lines they thought they had, that they cannot obtain the timely accommodation they presumably had paid for by good deposit behavior in the past. They are liquidity-constrained all of a sudden, in the sense that they need credit to carry out their investment and financial budgets. …… Just as the prevalence of liquidity-constrained unsatisfied borrowers in booms augments the power of tight money and credit crunches, so the relative absence of such borrowers in depressions and deep recessions weakens expansionary monetary policy. (Tobin (1978), pp.428-429)

Goodspeed (2026) provides historical evidence for such transmission mechanism of monetary policy.

The extent of indebtedness, bad assets and resultant "credit crunch" facing individual households and firms, we never know. That's true heterogeneity. HANK hardly captures such heterogeneity which plays crucial role in the transmission mechanism of monetary policy.

In passing, using micro panel data, Kuchler and Zafar (2019) report an interesting finding that expectations on *macro* variables such as housing prices and unemployment held by individual consumers depend strongly on their idiosyncratic past experiences. Such subjective expectations affect economic decisions of individual consumers, not observable regional housing price nor unemployment.

The point is that *even observed macro variables are not commonly shared by individual consumers so long as they affect economic decisions.*

Some economists might argue that we can group consumers by personal experiences. However, age, unemployment, and mortgage, for example, are only the tip of the iceberg, and the list of personal experiences is endless. If one exhausted such lists for all the consumers, what is left of macroeconomics? Simply, because we cannot observe personal experiences, we never observe micro behavior. This is the reason why we regularly obtain very low R squared in micro regression which necessarily uses observables as explanatory variables.

Contrary to their claims, alleged micro-foundations are false. In the next section, we consider Keynesian model based on statistical physics.

2. Macroeconomic Policy in Keynesian Model based on Statistical Physics

The theoretical framework in which we consider the effectiveness of macroeconomic policy is Keynesian model based on statistical physics. It is (old) Keynesian because *real aggregate demand* determines aggregate production.

Standard neoclassical theory takes technology, preferences, and factor endowments as exogenous. Keynes presented the vision that cyclical changes in aggregate economic activity, namely, quarter-to-quarter or year-to-year changes in real GDP, are basically determined by changes in *real* aggregate demand. This is the central message of Keynes (1936).

> The central Keynesian proposition is not nominal price rigidity but the principle of effective demand (Keynes, 1936, Ch. 3). In the absence of instantaneous and complete market clearing, output and employment are frequently constrained by aggregate demand. In these excess-supply regimes, agents' demands are limited by their inability to sell as much as they would like at prevailing prices. Any failure of price adjustments to keep markets cleared opens the door for quantities to determine quantities, for example real national income to determine consumption demand, as described in Keynes' multiplier calculus. …
>
> In Keynesian business cycle theory, the shocks generating fluctuations are generally shifts in real aggregate demand for goods and services, notably in capital investment (Tobin, 1993, 46-47).

The fundamental reason why *aggregate demand* becomes the most important determinant of macroeconomic activity in the short run is that aggregate demand can change swiftly, whereas factor endowment and technology change only slowly. The rate of utilization of production factors such as labor and capital endogenously change in response to changes in real demand. The challenge is then to clarify the market mechanism by which aggregate demand conditions the allocation of production factors in such a way that total output follows changes in real aggregate demand.

Theoretical Framework

In what follows, we explain micro-foundations for Keynesian economics based on the methods of statistical physics (Iyetomi (2012), Yoshikawa (2015, 2022, Ch.3)). It is important to recognize that this approach does not regard the behaviors of workers and firms as random. They certainly maximize their objective functions perhaps dynamically in their respective stochastic environments. Randomness underneath the entropy maximization comes from the fact that both the objective functions of and constraints facing a large number of economic agents are constantly subject to *unspecifiable* micro shocks. We must recall that the number of households is of order 10^7 or 10^8, and the number of firms, 10^6. Therefore, there is nothing for outside observers, namely, economists analyzing the macroeconomy but to regard a particular allocation *under macro constraints* as equiprobable. Then, it is most likely that the allocation of the aggregate demand and workers that maximizes the probability P_n *under macroconstraints* is realized.[3]

In the present model, the fundamental constraint on the economy as a whole is aggregate demand D. Accordingly, to each firm facing the downward-sloping *kinked individual demand curve,* the level of real demand for its product is the fundamental constraint. The problem is how the aggregate demand D is allocated to these monopolistically competitive firms with different productivity.

Suppose that N_k workers belong to firms whose productivity is c_k ($c_k < c_{k'}$ where $k < k'$). There are K levels of productivity in the economy ($k = 1, 2, \cdots, K$). The total number of workers N is given.

$$\sum_{k=1}^{K} N_k = N \tag{1}$$

A vector $N = (N_1, N_2, \cdots, N_K)$ shows a particular allocation of workers across firms with different productivities. The combinatorial number W_n of obtaining this allocation, N, is equal to that of throwing N balls to K different boxes. It is

$$W_n = \frac{N!}{\prod_{k=1}^{K} N_k!} \tag{2}$$

3 This method has been time and again successful in natural sciences when we analyze object comprising many micro elements. Economists might be still skeptical of the validity of the method in economics saying that inorganic atoms and molecules comprising gas are essentially different from optimizing economic agents. Every student of economics knows that behavior of dynamically optimizing economic agent such as the Ramsey consumer is described by the Euler equation for a problem of calculus of variation. On the surface, such a sophisticated economic behavior must look remote from "mechanical" movements of an inorganic particle which only satisfy the law of motion. However, every student of physics knows that the Newtonian law of motion is actually nothing but the Euler equation for a certain variational problem; particles minimize the energy or the Hamiltonian! It is called the principle of least action: see Chapter 19 of Feynmann (1964)'s *Lectures on Physics*, Vol. II. Therefore, behavior of dynamically optimizing economic agent and motions of inorganic particle are on a par to the extent that they both satisfy the Euler equation for respective variational problem. The method of statistical physics can be usefully applied not because motions of micro units are "mechanical," but because object or system under investigation comprises many micro unit individual movements of which we are unable to know.

Because the number of all the possible ways to allocate N different balls to K different boxes is K^N, the probability P_n that a particular allocation $N = (N_1, N_2, \cdots, N_K)$ is obtained is

$$P_n = \frac{W_n}{K^N} = \frac{1}{K^N} \frac{N!}{\prod_{k=1}^{K} N_k!}\,. \tag{3}$$

It is the fundamental postulate of statistical physics that the state or the allocation $N = (N_1, N_2, \cdots, N_K)$ that maximizes the probability P_n or (3) *under macro constraints* is to be realized. The idea is similar to maximum likelihood in statistics/econometrics.

Maximizing P_n is equivalent to maximizing $ln\, P_n$. Applying the Stirling formula for a large number$x$

$$ln\, x\,! \cong x\, ln\, x - x, \tag{4}$$

we find that the maximization of $ln\, P_n$is equivalent to that of S.

$$S = -N \sum_{k=1}^{K} p_k\, ln\, p_k \qquad\qquad (p_k = \frac{N_k}{N}) \tag{5}$$

S is the Shannon entropy and captures the combinatorial aspect of the problem. Although the combinatorial consideration summarized in the entropy plays a decisive role for the final outcome, that is not the whole story, of course. The qualification "under macro constraints" is crucial.

The first macro constraint concerns the labor endowment (1). The second macro constraint is that aggregate production or real GDP, Y is equal to aggregate demand, D. It consists of productions of many firms with different productivities c_k:

$$D = Y = \sum_{k=1}^{K} c_k N_k \tag{6}$$

Our problem is the allocation of labor$(N_1, N_2, \cdots, N_K)$. It is basically equivalent to the allocation of the aggregate demand to monopolistically competitive firms. Note, however, that for firms, demand is given, whereas employment is the outcome of firms' hiring efforts.

To maximize entropy S *under two macro constraints* (1) and (6), we set up the following Lagrangean form L:

$$L = -N \sum_{k=1}^{K} \left(\frac{N_k}{N}\right) ln \left(\frac{N_k}{N}\right) + \alpha[N - \sum_{k=1}^{K} N_k] + \beta[D - \sum_{k=1}^{K} c_k N_k] \tag{7}$$

with two Lagrangean multipliers, α and β. Maximization of this Lagrangian form with respect to N_k leads us to the first-order conditions:

$$ln\left(\frac{N_k}{N}\right) = -1 - \alpha - \beta c_k \quad (k = 1,\ 2,\ \cdots,\ K) \tag{8}$$

which are equivalent to

$$\frac{N_k}{N} = exp[-1 - \alpha - \beta c_k]. \tag{9}$$

Because N_k/Nsums up to one, we obtain

$$\frac{N_k}{N} = \frac{e^{-\beta c_k}}{\sum_{k=1}^{K} e^{-\beta c_k}} \tag{10}$$

Thus, the number of workers working at firms with productivity c_k is exponentially distributed. It is known as the Boltzmann distribution in physics.

Here arises a crucial difference between economics and physics. In physics, c_k corresponds to the level of energy. Whenever possible, particles tend to move toward the *lowest* energy level. In contrast, in economics, workers always strive for better jobs offered by firms with higher productivity c_k. As a result of optimization under unobservable micro constraints, workers move to better jobs. In fact, if allowed, all workers would move up to the job sites with the highest productivity, c_K. This situation shown in Figure 2 corresponds to the textbook Pareto optimal equilibrium with no frictions and uncertainty.

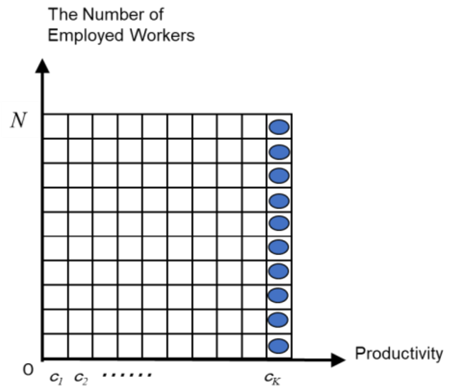

Figure 2: All Workers Work at Job sites with the Highest Level of Productivity under Extremely High Aggregate Demand, D_{max}

However, this state is actually impossible unless the level of aggregate demand D is so high as equal to the maximum level D_{max} defined as $c_K N$. Only when D is equal to D_{max}, demand-constrained firms with the highest productivity face high enough individual demand curves so that they have incentives to employ N workers. On the part of workers, they would be able to find job sites with the highest productivity because firms with c_K try hard to keep their existing workers and, at the same time, post enough vacancy signs and make aggressive hiring efforts. The maximum level of aggregate demand D_{max} is only imaginary, however. When D is lower than D_{max}, the story is quite different. Some workers —— a majority of workers, in fact, must work at job sites with productivity much lower than c_K.

How are workers distributed over job sites with different productivity? It depends on the level of aggregate demand. When D reaches its lowest level, D_{min}, workers are distributed evenly across all sectors with different levels of productivity, $c_1, c_2, \cdots, c_K$ (Figure 3). Here, D_{min} is defined as $D_{min} = N(c_1 + c_2 +, \cdots, + c_K)/K$. It is easy to see that the lower the level of D is, the greater the combinatorial number of the distribution $(N_1, N_2, \cdots, N_K)$ that satisfies the aggregate demand constraint (6) becomes.

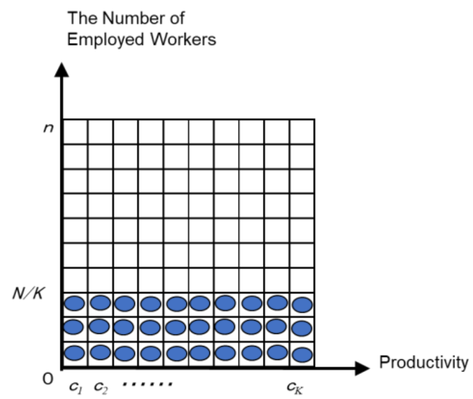

Figure 3: Workers are Distributed Evenly across All Sectors with Different Levels of Productivity under Extremely Low Aggregate Demand, D_{min}

As explained above, the combinatorial number W_n of a particular allocation $N = (N_1, N_2, \cdots, N_K)$ is basically equivalent to the Shannon entropy, S defined by (5). S increases when D decreases. In the extreme case where D is equal to or greater than the maximum level D_{max}, all the workers work at job sites with the highest productivity because whenever possible, workers move to better job sites with higher productivity (Figure 2). In this case, the entropy S becomes zero, its lowest level because $N_K/N = 1$ and $N_k/N = 0 \quad (k \neq K)$. In the other extreme where aggregate demand is equal to the minimum level D_{min}, we have $N_k = N/K$ (Figure 3), and the entropy S defined by (5) becomes $ln\, K$, its maximum level.

Thus, the relation between the entropy S and the level of aggregate demand D resembles the relation shown in Figure 4. In the present model, entropy basically corresponds to the dispersion of job quality in the labor market, which in turn comes from the dispersion of demand facing firms in the product market. Workers face greater uncertainty and friction when the level of aggregate demand is low because the dispersion of job quality becomes larger in that case. Low-productivity firms can attract workers, as high-productivity firms facing more stringent demand constraints make fewer job openings under lower aggregate demand.

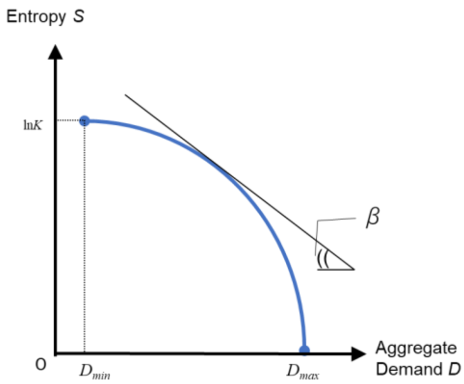

Figure 4: Entropy S and Aggregate Demand D

At this stage, we can recall that the Lagrangean multiplier β in (7) for the aggregate demand constraint is equal to

$$\beta = \frac{\partial L}{\partial D} = \frac{\partial S}{\partial D}. \tag{11}$$

β is the slope of the tangent of the curve, as shown in Figure 4, and is therefore negative (Iyetomi (2012))[4]. With negative β, the exponential distribution (10) is upward-sloping.

The maximization of entropy under the aggregate demand constraint (7), in fact, balances two forces. On the one hand, whenever possible, workers move to better jobs identified with job sites with higher productivity here. It is the outcome of successful job matching resulting from the worker's search and the firm's recruitment. When the level of aggregate demand is high, this force dominates. However, when D is lower than D_{max}, there are in general a number of different allocations $(N_1, N_2, \cdots, N_K)$ that are consistent with D.

As we explained previously, micro shocks facing both workers and firms are truly unspecifiable. We simply do not know which firms with what productivity face how much demand constraint and

[4] In physics, β is positive in most cases. This difference arises because workers strive for job sites with higher productivity, not the other way round (Iyetomi (2012)). In physics, β is equal to the inverse of temperature, or more precisely, temperature is defined as the inverse of $\partial S / \partial D$ when S is the entropy and D energy. Thus, negative β means the *negative temperature*. It may sound odd, but the notion of negative temperature is perfectly legitimate in such systems as the one in the present analysis. In particular, the number of possible levels of energy must be finite; see Appendix E of Kittel and Kroemer (1980). In our present case, the level of productivity is plainly finite.

need to employ how many workers with what qualifications. We do not know which workers are seeking what kind of jobs with how much productivity, either. Here comes the maximization of entropy. This gives us the distribution $(N_1, N, \cdots, N_K)$, which corresponds to the maximum combinatorial number consistent with a given D.

The entropy maximization under the aggregate demand constraint plays, therefore, a role similar to that of the matching function in standard search theory. Note that unlike the standard matching function, which focuses only on the number of jobs, the matching of *job quality* characterized by productivity plays a central role in the present analysis. The matching function presumes that the number of job matches increases when the numbers of unemployed individuals and vacancies increase. In the present analysis, the matching of high productivity jobs is ultimately conditioned by the level of aggregate demand because high aggregate demand loosens demand constraints facing monopolistically competitive high productivity firms, and *vice versa*. *Uncertainty and frictions emphasized by standard search theory are not exogenously given but depend crucially on aggregate demand*. In a booming gold-rush town, one does not waste a minute finding a good job. The opposite holds true in a depressed city. The higher the level of aggregate demand D is, the more workers are mobilized to jobs with higher productivity (Okun 1973).

3. Effectiveness of Macroeconomic Policy

We study effectiveness of macroeconomic policy by modifying Keynesian model based on statistical physics explained in the previous section. For this purpose, we generalize the assumption on aggregate demand, whereas we simplify the assumption on distribution of productivity by restricting $K = 2$. There are only two levels of productivity, high and low.

Aggregate demand AD consists of two components D, and $\widetilde{D} = (N_1 a + N_2 b)$:

$$AD = D + \widetilde{D} = D + N_1 a + N_2 b \tag{12}$$

The first term D is the aggregate level of unobservable micro demand which corresponds one to one to entropy. As we explained above, it plays a role similar to that of the matching function in standard search theory. When D is high, workers are mobilized in a "thermal" way to high productivity jobs / firms / sectors, and *vice versa*. This is exactly the process Okun (1973) described using his "ladder" model.

The second term $\widetilde{D}$, on the other hand, is a part of aggregate demand which is induced by observable macro shocks including the implementation of macroeconomic policy. The parameters *a* and *b* in equation (12) represent the degree to which labor is induced to high and low productivity sectors, respectively by macro shocks. In a popular example found in any thermodynamics textbook, D corresponds to heat bath which determines temperature of system or "cylinder" under investigation, while $\widetilde{D}$ corresponds to piston.

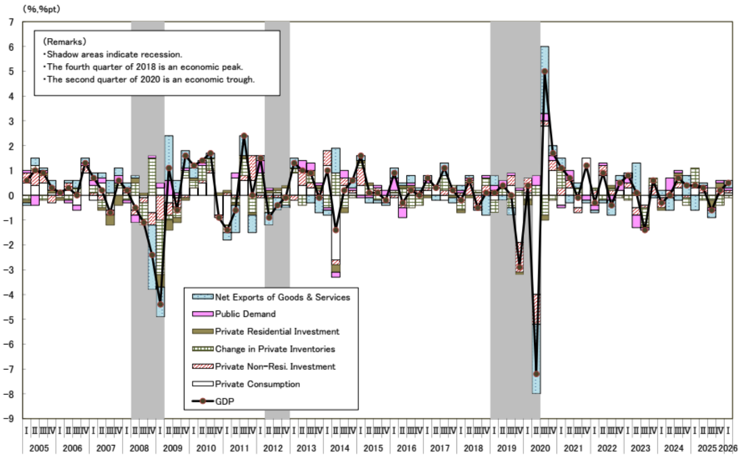

Figure 5: Quarterly Growth Rates of Japan's GDP: 2005.I – 2026.I.
Source: Cabinet Office

Figure 5 shows quarterly growth rates of Japan's real GDP during the period of 2005.I – 2026.I. Quarterly fluctuations, ups and downs in the figure, are nothing but the outcome of countless micro decisions made by many households and firms. They are unobservable, but conditioned fundamentally by the level of aggregate demand or D. Nirei (2023) attempts to provide micro-foundations for such interaction – driven macroeconomic fluctuations. Although interaction-driven macroeconomic fluctuations are certainly there, we maintain that to provide micro-foundations for such fluctuations is on the wrong track. One can usefully recall Slutsky (1937) who demonstrated that the summation of purely random micro events can generate cyclical macro fluctuations.

In any case, Figure 5 demonstrates the presence of several major fluctuations visually distinct from other minor fluctuations; The sharp decline of growth rate in 2008 was the global financial crisis, and the fall in 2020 was caused by the COVID 19 panic. They are *observable macro shocks* fundamentally different from *unobservable micro shocks*. In the present model, the level of aggregate demand conditioning micro shocks is D whereas observable macro shocks are $\widetilde{D}$. The level of total aggregate demand AD is $D + \widetilde{D}$ (equation (12)).

In this new setting, we maximize entropy S under three macroeconomic constraints:

$$N_1 + N_2 = N \tag{13}$$

$$Y = c_1 N_1 + c_2 N_2 = AD = D + \widetilde{D} = D + (N_1 a + N_2 b)$$
$$(c_1 < c_2) \tag{14}$$

$$\widetilde{D} = N_1 a + N_2 b \tag{15}$$

where N and D are given. The Lagrangian form L is as follows.

$$L = -N\left\{\left(\frac{N_1}{N}\right)\log\left(\frac{N_1}{N}\right) + \left(\frac{N_2}{N}\right)\log\left(\frac{N_2}{N}\right)\right\} + \alpha\{N - (N_1 + N_2)\}$$
$$+\beta\{D + (N_1 a + N_2 b) - (c_1 N_1 + c_2 N_2)\}$$
$$+\gamma\{\widetilde{D} - (N_1 a + N_2 b)\} \tag{16}$$

The maximization of entropy determines the distribution of labor across job sites/firms/sectors with different productivity, and thereby the aggregate level of production, or Y.

We obtain the following total differential equation:

$$dS = \alpha dN + \beta dD + \gamma d\widetilde{D} \tag{17}$$

Regarding the total income Y as the internal energy in a physical system, we have a more familiar form in the thermodynamics:

$$dY = \frac{1}{\beta} dS - \frac{\alpha}{\beta} dN + \left(1 - \frac{\gamma}{\beta}\right) d\widetilde{D} \tag{18}$$

The internal energy of "cylinder" Y changes by three factors on the right-hand side, namely, "heat", "the number of particles" and the effect of "piston", or outside force. The effect of policy corresponds to "piston", $d\widetilde{D}$.

We see that

$$1 - \frac{\gamma}{\beta} = \frac{\partial Y}{\partial \widetilde{D}} \tag{19}$$

represents the impact of macro demand shock $\widetilde{D}$ on Y.[5]

The maximization of L with respect to N_1 and N_2 leads us to

$$\frac{N_1}{N} = \frac{e^{\beta(a-c_1)-\gamma a}}{e^{\beta(a-c_1)-\gamma a} + e^{\beta(b-c_2)-\gamma b}} \tag{20}$$

$$\frac{N_2}{N} = \frac{e^{\beta(b-c_2)-\gamma b}}{e^{\beta(a-c_1)-\gamma a} + e^{\beta(b-c_2)-\gamma b}} \tag{21}$$

Therefore, the expected value of $\widetilde{D}$, $\langle\widetilde{D}\rangle$ is

[5] In physics, $1 - \gamma/\beta$ serves as the generalized force conjugate to $\widetilde{D}$.

$$\langle \widetilde{D} \rangle = N \frac{ae^{\beta(a-c_1)-\gamma a} + be^{\beta(b-c_2)-\gamma b}}{e^{\beta(a-c_1)-\gamma a} + e^{\beta(b-c_2)-\gamma b}} \tag{22}$$

When γ is equal to β, (20) and (21) reduce to the probability distribution (10) obtained without macro shocks or the implementation of macroeconomic policy. We note that increase of $\langle \widetilde{D} \rangle$ induced by the policy impact means a shift in the distribution of workers from lower to higher productivity levels.

Expanding the right-hand side of (22) with respect to γ around $\gamma = \beta$ and retaining up to the first order term, we obtain

$$\frac{\langle \widetilde{D} \rangle}{N} = \frac{a+be^{\Delta}}{1+e^{\Delta}} + \beta \frac{(a-b)^2 e^{\Delta}}{(1+e^{\Delta})^2} \left(1 - \frac{\gamma}{\beta}\right) \tag{23}$$

where Δ is the reduced economic temperature defined by

$$\Delta = \beta(c_1 - c_2)\,. \tag{24}$$

Note that Δ is positive because β is negative, and c_2 is greater than c_1. Recalling that the force of macro shock including macroeconomic policy is represented by $1 - \gamma/\beta$, we find that *the effectiveness of macroeconomic policy* is measured by the coefficient of $1 - \gamma/\beta$ in (23), namely χ defined as follows:

$$\chi = \beta \frac{(a-b)^2 e^{\Delta}}{(1+e^{\Delta})^2} \tag{25}$$

We can easily confirm that χ is proportional to $f(\Delta)$ defined by following equation (26).

$$f(\Delta) = \frac{(c_1-c_2)\chi}{(a-b)^2} = \frac{\Delta e^{\Delta}}{(1+e^{\Delta})^2} \tag{26}$$

Note that Δ depends on β or D (equation (24)).

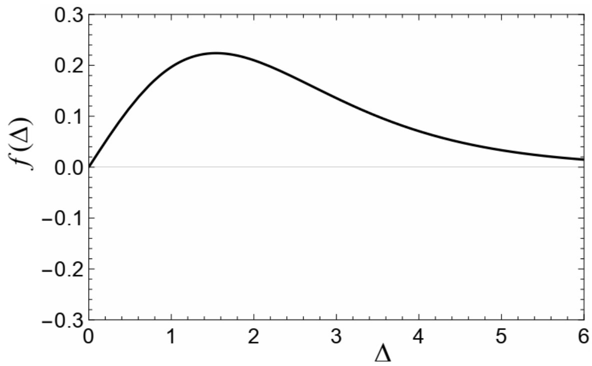

Figure 6: The effectiveness of macroeconomic policy depends on the level of aggregate demand, or temperature Δ.

Note that the negative temperature region corresponds to $\Delta > 0$ with $c_1 < c_2$.

Figure 6 shows $f(\Delta)$which measures the effectiveness of macroeconomic policy. It starts from the origin, goes upward, reaches its peak, and then goes gradually downward as Δ increases. The shape of $f(\Delta)$ has remarkable implications for the effectiveness of macroeconomic policy. We must recall that Δ is proportional to β, and therefore, corresponds one to one to entropy S as shown in Figure 4. It is an indicator of aggregate demand D; The higher Δ is, the higher D is.

Now, Figure 6 shows that when D is high, $f(\Delta)$ is a decreasing function of Δ. This is natural because when D becomes very high, there is little room left for further expansion even if macroeconomic policy is implemented.

A more relevant case is the region left of peak of $f(\Delta)$. Here, $f(\Delta)$ is an increasing function of Δ. When aggregate demand is high in this region, namely close to the peak, $f(\Delta)$ is high. It means that macroeconomic policy is effective. An increase of $\widetilde{D}$ brings about an increase of GDP or Y as one would expect. However, when D is very low, namely, Δ is close to the origin, $f(\Delta)$ becomes small in Figure 6. In fact, it approaches zero as Δ becomes zero. Macroeconomic policy becomes ineffective.

When Δ or β is close to zero, entropy S is high; See Figure 4. Aoki (2002) explains that in individual decision makings, the higher entropy is, the greater uncertainty microeconomic agents face. In the macroeconomy, when uncertainty is great, consumers and firms hardly respond to policy, and as a consequence, macroeconomic policy becomes ineffective. We can reasonably say that the economy falls into *uncertainty trap*.

4. Concluding Remark

It has been widely recognized that uncertainty hinders the macroeconomy. The poor performance of the economy following the 2008 global financial crisis revived once forgotten “secular stagnation”, and produced vast literature on uncertainty. Empirical macroeconomics explores how to measure uncertainty besides such popular measure as stock price volatility, and then checks whether uncertainty independently hinders the macroeconomy. Morikawa (2019) reviews the literature and provides an empirical analysis using Japanese monthly survey data.

A related problem of great importance is effectiveness of macroeconomic policy. Under the apparent constraint of zero interest bound, effectiveness of monetary policy has been widely analyzed. However, they are all based on the crucial assumption that economic agents share the same stochastic constraints, and are not worthy of properly micro-founded macroeconomics.

To take care of *heterogeneity* of economic agents, literally indispensable is the concept of *entropy* which plays the central role for analyzing any macro system in natural sciences. We advanced Keynesian model based on the methods of statistical physics. We showed that in such model, uncertainty necessarily weakens the effectiveness of macroeconomic policy.

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