real-world economics review, issue no. 77
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The mathematical equivalence of Marshallian analysis and "general equilibrium" theory

Philip George [India]

Abstract
In this paper we explore general equilibrium (GE) theory. We demonstrate that (a) Marshallian demand analysis is no less general in its implications, though this is masked by the way static analysis is framed and (b) that an unstated assumption of GE theory is that aggregate demand is constant. Together, these two results imply that, shorn of the complicated math, GE theory is equivalent to Marshallian demand analysis. It also explains why the two arrive at identical results on subjects like involuntary unemployment. This in turn, has implications for how we view the work of Keynes as well as current issues in economics, such as the legacy of formalism, and the relevance of new classical economics, dynamic stochastic general equilibrium (DSGE) and real business cycle theory.

Keywords: general equilibrium theory, Kenneth Arrow, macroeconomics, Marshallian economics

JEL Classifications: E12, E13

Introduction

A form of Alfred Marshall's work is still present in general textbooks and historians of economic thought continue to debate the significance and achievements of Marshall. On this basis it is perhaps possible to distinguish between "Marshallian" as an interpretation and use of his legacy and the context, intentions, limits etc. of his *Principles*. For a long time now it has been customary for economists to think of Marshall's work as a relic from a mathematically-challenged era. This is in so far as static analysis for partial equilibrium is superseded by general equilibrium (GE) theory. It is now also widely recognized that GE theory is problematic in various ways. Modern mainstream economics cannot be reduced to it. However, it remains influential both as a point of reference for theory and as a standard for formalism as an important mode of expression within economics. Moreover, GE has been highly influential during the period in which Keynes' work and the concept of involuntary unemployment have been distorted or suppressed. With these issues in mind, in the following short paper I make three important points:

1. Marshallian demand analysis as partial equilibrium necessarily involves effects on all markets and so is equivalent to GE;
2. GE theory does not disprove the existence of involuntary unemployment, rather it assumes it out of existence. Notably, aggregate demand is assumed to be constant.
3. However, the most reasonable explanation of unemployment within GE is still always likely involving involuntary unemployment, due to the cumulative impact of even small disequilibria on the special (if unacknowledged) status of the labour market as the largest (and in a generalised sense pervasive) market.

The underlying point made is that GE is not a significant improvement on partial equilibrium. It is rather part of the way in which Keynesian approaches have been disadvantaged or

distorted. Keynes' work remains relevant. Keynes' own words in the *General Theory* on the battle between Ricardian and Malthusian ideas seem relevant here:

> "Ricardo conquered England as completely as the Holy Inquisition conquered Spain. Not only was his theory accepted by the city, by statesmen and by the academic world. But controversy ceased; the other point of view completely disappeared; it ceased to be discussed" (Keynes, 1936).

The argument is made drawing heavily on Arrow's work on GE, since Arrow is careful to state the key assumptions. Since the paper is brief, and the aspects of Arrow's work drawn on relate closely to mathematical expression, extensive sections of his work are reproduced here.

A. The generality of general equilibrium theory

One of the principal claims of GE theory is that it takes all markets into simultaneous consideration and thus more realistically reflects the interconnectedness of all markets in the economy than Marshallian economics, which deals only with one isolated market at a time and is thus a case of partial equilibrium.

However, Marshallian demand analysis too deals with the economy as a whole and is thus no less general than GE theory. This is not typically acknowledged within Marshallian analysis, though, as I will show, the assumptions made in the construction of each market have consequences for all others. Clearly, GE differentiates itself on the basis of the actual intent of the theory, but this does not mean the two lack equivalence.

Kenneth Arrow's Nobel Memorial Lecture (Arrow, 1972) sets out the GE argument:

> "The consumer starts with the possession of some quantities of economically valuable goods, such as labor of particular types, land, or other possessions. Let us imagine there are n commodities altogether, and let $\bar{x}_{hi}$ be the amount of commodity i owned initially by individual h (this may well be zero for most commodities). If p_i is the price of the i^{th} commodity, then his total income available for expenditure is
>
> $$\sum_{i=1}^{n} p_i \bar{x}_{hi} \qquad (1)$$
>
> "Hence, he can choose for consumption any bundle of goods, $x_{h1}, \ldots, x_{hn}$, which cost no more than his income,
>
> $$\sum_{i=1}^{n} p_i x_{hi} \leq \sum_{i=1}^{n} p_i \bar{x}_{hi} \qquad (2)$$
>
> "Within this budget set of possible consumption bundles, the individual is presumed to choose his most preferred bundle... The most preferred bundle then is a function,
>
> $$x_{hi}(p_1, \ldots, p_n) \qquad (3)$$

> of all prices. Notice that, from this viewpoint, all prices clearly enter into the determination of the demand for any one commodity. For one thing, the rise in any one price clearly diminishes the residual income available for all other commodities. More specifically, however, the demands for some commodities are closely interrelated with others; thus, the demand for gasoline is perhaps more influenced by the use of automobiles and therefore by their price than it is by its own price. The interrelation of all demands is clearly displayed here" (Arrow, 1972).

The idea that general equilibrium theory is superior to alternative methods is clearly stated in the subsequent literature. For example:

> "The Walrasian [general equilibrium] theory has the capacity to explain the influence of taste, technology, and the distribution of wealth and resources on the determination of value. Nothing that came before the Walrasian theory had this capacity. Neither partial equilibrium theory nor theories that depend on technology and resources alone provide as strong an explanation of value. Although, for certain markets, it is possible to explain how price responds to small parameter changes with partial equilibrium reasoning, few economists would contend that this method is adequate when economies are disturbed in a major way" (Duffie and Sonnenschein, 1989).

Or again, a little later:

> "The essence of general equilibrium does not preclude aggregation; what is essential is an emphasis on inter-market relations and the requirement that variables are not held fixed in an ad hoc manner" (Duffie and Sonnenschein, 1989).

We turn next to Marshallian demand curves to see if this claim to significant difference is true.

Figure 1 below shows a linear demand curve for the fish markets.

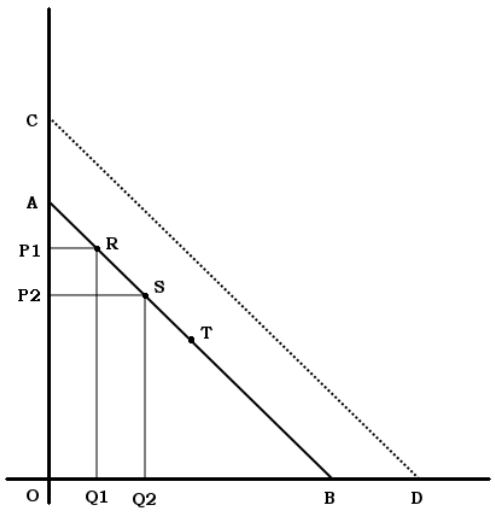

Fig 1. Linear demand curves for fish

The original demand curve is AB. The demand curve is drawn assuming that people's incomes are constant as are their tastes. If people's incomes increase then at every price they can buy more fish and the demand curve moves to CD. Similarly, if people develop an increased taste for fish the demand curve moves up.

T is the midpoint of the demand curve. The segment AT is the elastic zone. The segment TB is the inelastic zone.

Assume that the initial equilibrium is at point R (in the elastic zone) where the price is P1 and the quantity sold is Q1. Assume also that at this point individuals spend all their income and do not save anything. Next suppose that because of a movement of the supply curve the price falls to P2, also in the elastic zone, as a result of which the equilibrium moves to S. The quantity of fish bought increases to Q2. We can also see from the graph that the money spent on fish rises; the initial amount spent is the area of OP1RQ1 and the final amount spent is the area of OP2SQ2.

But here we run into a problem. We had assumed that individuals spent all their income at the first equilibrium point R and now we find them spending a larger amount on fish at S. This can happen only if they spend a smaller amount on some other good or goods so as to maintain their spending constant.

To summarize, along the elastic portion of a linear demand curve, when the price of fish falls not only does the quantity of fish bought increase but the money spent on fish also increases. So the money spent in other markets has to fall so as to maintain our initial assumption of a constant income. In general, the money spent at any point on the demand curve is different from that spent at any other point. To compensate for this difference the money spent in other markets, and therefore the demand and price in those markets, have to change.

This feature of linear demand curves also applies to demand curves of other shapes, with a solitary exception: the rectangular hyperbola PQ = constant. An analysis involving the rectangular hyperbola is too complex to be gone into here.

What is true of the fish market is also true of *every other* Marshallian market. When the price and demand for any good changes it affects demands and prices in other markets.

So it is clearly not the case that the Marshallian demand curve is drawn on the assumption that demands and prices in all other markets are constant. The Marshallian analysis is, therefore, no less general than General Equilibrium analysis. The charge is that in the Marshallian analysis, the individual's demand for the i[th] commodity is $x_{hi}(p_i)$ whereas in reality it is $x_{hi}(p_1, \ldots, p_n)$ which is the demand for good i in GE theory. The two are in this sense, other claims apart, equivalent.

B. General equilibrium theory and involuntary unemployment

In his Nobel lecture Arrow describes the various stages by which GE theory arrives at an equilibrium that is also Pareto efficient. But after the proof is done he mentions a caveat:

> "There is one loose end that should now be picked up. It has been assumed that the demand functions of the individual are continuous. But one of the surprising discoveries that [Gerard] Debreu and I made in the course of our study was that even under all the usual strong assumptions about the behavior of individuals, this cannot be true everywhere in the price simplex except under very artificial conditions. The trouble is that the individual's income also depends upon prices, and if the prices of those commodities which the individual owns originally fall to zero, his income falls to zero. When some prices and income are zero, however, the demand for the now-free goods may jump discontinuously. To illustrate, suppose an individual owned initially only one good, say, labor. So long as the price of that good was positive, he might retain some for his own use, but in any case could never consume more than he had initially. But when the price fell to zero, he could demand the same labor from others and in any amount he chooses. The existence of competitive equilibrium then does depend on assumptions which insure that for each individual there is at least one commodity he owns initially which is bound to have positive value" (Arrow, 1972).

Duffie and Sonnenschein's paper provides further elaboration. They quote Arrow:

> "Debreu and I sent our manuscripts to each other and so discovered our common purpose. We also detected the same flaw in each other's work; we had ignored the possibility of discontinuity when prices vary in such a way that some consumers' incomes approach zero. We then collaborated, mostly by correspondence, until we had come to some resolution of this problem." D&S go on to explain: "This resolution was to require, in theorem 1 of their paper, that the initial endowment of each household be interior to its consumption set. (Arrow had faced a difficulty much related to the demand discontinuity problem in his earlier work on the second welfare theorem)" (Duffie and Sonnenschein, 1989).

But if the existence of a general equilibrium requires ruling out a situation when a consumer's initial endowment has a market price of zero it *also* requires ruling out a situation when the consumer possesses only a single commodity and is unable to sell it because this would practically mean that he had no initial endowment. When the commodity in question is labour the situation is, of course, what we call involuntary unemployment. That is to say, labour has a market price but not all consumers who possess it can find a buyer.

So, contrary to what at least some GE theorists would have us believe, GE theory *does not disprove the existence of involuntary unemployment*. Rather, for GE to exist, *involuntary unemployment must first be assumed out of existence*. General equilibrium can exist only if its assumptions guarantee that the labour market has no disequilibrium. And yet GE is also an equilibrium seeking theory. Marshallian demand analysis logically arrives at the conclusion that involuntary unemployment is impossible, but GE theory needs to assume it in the first place to ensure general equilibrium. The equivalence between the two approaches thus involves some difference, but the difference does not enhance the credentials of GE.

C. General equilibrium theory and unemployment

Apart from consumption, GE theory also takes production into consideration.

To quote from Arrow's Nobel lecture again:

> "A productive unit or firm is characterized by a relation between possible outputs and inputs. A firm may have, of course, more than one output. Then firm f may be characterized by its transformation surface, defined by an equation, $T(y_{f1}, \dots, y_{fn}) = 0$, where y_{fi} is taken to be an output if positive and input if negative; the surface is taken to define the efficient possible input-output vectors for the firm, that is, those which yield maximum output of one commodity for given inputs and given outputs of other commodities. The optimizing behavior of the firm is taken to be the maximization of profit among the points on its transformation surface. Because of the sign conventions for inputs and outputs, the firm is seeking to maximize,

$$\sum_{i=1}^{n} p_i y_{fi} \qquad (4)$$

And a little later:

> "For any commodity i, there will be some demands and some supplies at any given set of prices. Following Hicks, we will speak of the *excess demand* for commodity i as the sum over all individuals and firms of demands and supplies, the latter being taken as negative. The demand by individual h is $x_{hi}(p_1, \dots, p_n)$, so that the total demand by all households is

$$\sum_{h} x_{hi}(p_1, \dots, p_n) \qquad (5)$$

> "The supply by households is the aggregate amount they have to begin with, i.e.,

$$\sum_{h} \bar{x}_{hi} \qquad (6)$$

> "Finally, the aggregate demand by firms is

$$\sum_{f} y_{fi}(p_1, \dots, p_n) \qquad (7)$$

> some firms may be demanders rather than suppliers, but the sign convention assures that the above sum gives the aggregate net supply by firms, i.e., after cancelling out demands by one firm which are supplied by another.

> "... Further, the satisfaction of the budget constraint for each individual also restricts the excess demand functions. Since for each individual, the monetary value of expenditure planned at any set of prices equals the monetary value of his initial endowments plus his share of the profits, we

have in the aggregate that the money value of planned expenditure by all households equals the money value of total endowments plus total profits, or

$$\sum_h \sum_{i=1}^{n} p_i x_{hi}(p_1, \dots, p_n) = \sum_h \sum_{i=1}^{n} p_i \bar{x}_{hi} + \sum_f \sum_{i=1}^{n} p_i y_i(p_1, \dots, p_n) \qquad (8)$$

or, from the definition of excess demand,

$$\sum p_i z_i(p_1, \dots, p_n) \equiv 0 \qquad (9)$$

[z_i is the market excess demand for commodity i] where the identity symbol reminds that this relation, called by Lange [1942] Walras' Law, holds for all values of the prices."

With those definitions in place and a long discursion through more math we come to the section "The Existence of Competitive Equilibrium"

> "A set of prices defines a competitive equilibrium if supply and demand balance on each market, including the possibility of corners, with *some* choice of the profit-maximizing input-output vector for each firm. Formally, we will say that a price vector p^*, an input-output vector y_f^* for each firm, and a consumption vector, $x_h^* = x_h(p^*)$, for each individual together constitute a competitive equilibrium if the following [four] conditions hold" (Arrow, 1972).

We are concerned here with the second condition.

> "(b) for each commodity i,
>
> $$\sum_h \bar{x}_{hi} + \sum_f y_{fi}^* \geq \sum_h x_{hi}^*" \qquad (10)$$

This is a straightforward conservation law. In plain English it says that the total demand of a commodity by households must be less than or equal to the sum of the initial holding of that commodity by households together with the output of that commodity by firms.

This applies to any commodity; therefore it must also apply to labour. Since households are suppliers of labour but not consumers of labour the right hand side of the above equation is equal to zero and the first term on the left hand side is positive. Similarly, since firms are consumers but not suppliers of labour the second term on the left hand side is negative.

So the equation above tells us that *the supply of labour will always be equal to or greater than the demand for labour*. This curious result derived from the equations of GE theory is in complete accord with reality (with the sign in practice being one of inequality) because we know that even in economies that are not undergoing a recession, there is a certain amount of unemployment, which is sought to be explained under the rubrics of frictional unemployment, non-accelerating inflation rate of unemployment, search-match delays and so on.

However, the equation allows a simpler, more logical explanation for such unemployment. Most households have only the single commodity called labour to sell. On the other hand, nearly all firms in all industries have to buy greater or lesser quantities of labour. Labour is the largest market in the economy. Compensation paid to employees in the US amounts to about 44% of GDP at present (St Louis Federal Reserve, 2016). So even when every market is only *slightly displaced from equilibrium*, to an extent that the disequilibrium is barely perceptible, the small displacements from perfect equilibrium in every market will be cumulative. That is, in the case of the input, labour, unemployment will amount to a relatively large proportion of the labour market, say, of the order of 5% in the US. The constant presence of unemployment is actually proof that the economy is always in the process of attaining equilibrium but never quite there. It is not credible to suggest this is entirely a matter of frictions, churning, and matching. There will always be more or less involuntary unemployment.

Unfortunately, this explanation is not permitted by the rules of GE theory, since equilibrium is attained.

To quote from Arrow's Nobel lecture again, the third condition for equilibrium is "(c) for any commodity for which the strict inequality holds in (b) [eqn 10], we must have $p_i^* = 0$" (Arrow, 1972)

Now this condition has been used earlier to account for the case of free goods. For example, the supply of air is greater than the demand for air, so its price must be zero. By that token, if the supply of labour is greater than the demand for air, its price must be zero.

We come away with the impression that GE theorists do not wish to listen to what their own equations are telling them but prefer to torture them so that the equations say what the theorists want to hear, viz. that the economy is in equilibrium.

D. The relationship between supply and demand

Again, in this section an extensive extract from Arrow's Nobel lecture is required. To get a proper grasp of the context it is advisable to read the complete speech, though it is not needed for our purpose.

> "We begin to see that a Pareto efficient allocation is an equilibrium of supply and demand in the generalized sense which includes corners. We also see that,
>
> $$\sum_{i=1}^{n} p_i(z_i - z_i^0) \geq 0 \quad for\ z\ in\ Z \qquad (11)$$
>
> [z_i is the excess demand vector for commodity i, Z is the set of all excess demand vectors and the superscript 0 refers to the Pareto-optimal case.]
>
> "Let us go back to the definition of excess demand, as a sum of individual and firm demands and supplies.

$$z_i = \sum_h x_{hi} - \sum_h \bar{x}_{hi} - \sum_f y_{fi} \qquad (12)$$

where $y_f = (y_{f1}, \dots, y_{fn})$ is a technologically possible vector of inputs and outputs for firm f and $x_h = (x_{h1}, \dots, x_{hn})$ is a possible vector of consumptions for individual h. In particular, the excess demands defined by the Pareto efficient allocation can be written in this form,

$$z_i^0 = \sum_h x_{hi}^0 - \sum_h \bar{x}_{hi} - \sum_f y_{fi}^0 \qquad (13)$$

and then, if z belongs to Z, we must have, for each h, that the consumption vector of individual h, $(x_{h1}, \dots, x_{hn})$ is preferred to that under the Pareto efficient allocation $(x_{h1}^0, \dots, x_{hn}^0)$. Then,

$$\sum_h (\sum_{i=1}^n p_i x_{hi} - \sum_{i=1}^n p_i x_{hi}^0) - \sum_f (\sum_{i=1}^n p_i y_{fi} - \sum_{i=1}^n p_i y_{fi}^0) \gg 0 \qquad (14)$$

if, for each h, x_h is preferred by individual h to x_{hi}^0.

"Now the elementary point about this inequality is that the variable vectors x_h, y_f are independent of each other. It is not hard to see that this inequality can hold only if it holds for each individual and each firm separately. For a firm f, this means that,

$$\sum_{i=1}^n p_i y_{fi}^0 \geq \sum_{i=1}^n p_i y_{fi} \text{ for all possible } y_f \qquad (15)$$

that is, if we interpret the $p_i's$ as prices, each firm is maximizing its profits. The corresponding interpretation for individuals is somewhat less simple; it is that the consumption vector prescribed by the given Pareto efficient allocation is the cheapest way of deriving that much satisfaction" (Arrow, 1972).

The details of the above derivation are not so important as the assumption that makes it possible:

> "Now the elementary point about this inequality is that the variable vectors x_h, y_f are independent of each other" (Arrow, 1972).

In Section A we established that GE theory and Marshallian demand analysis are equivalent. In this sense, GE does not represent an advance over Marshallian demand analysis. However, if we consider the assumption above, that consumption and production are independent of each other, it seems clear that GE introduces conditions that are a giant step backwards compared with Keynesian theory.

Indeed, I think I exaggerate only a little if I say that the central purpose of writing *The General Theory* was to show that consumption and production are not independent of each other as

classical economics had assumed. This would of course have been clearer if Keynes' legacy had not focused to such a great degree on the issue of investment.

It requires quite some flexing of the imagination to believe that the demand for bread is dependent on the price of steel, but it requires no imagination at all to perceive that the output of steel affects the demand for bread, by affecting the incomes paid out to labour involved in the production of steel. The demand for bread is a weak function of the price of steel. The demand for bread is also a weak function of the output of steel, but it is probably a stronger function than the first. So, the problems of GE theory can be traced to its fundamental assumptions.

GE theory assumes that the individual's demand for commodity i is $x_{hi}(p_1, \dots, p_n)$ whereas in reality it is $x_{hi}(p_1, \dots, p_n, y_{f1}, \dots, y_{fn})$. When aggregate income is constant the cross effects cancel out so that the first expression can be taken as a good approximation. This is because we are primarily interested in how demand *changes* in response to *changes* in prices, and vice versa. Similarly the firm's demand for commodity i in the general case is not $y_{fi}(p_1, \dots, p_n)$ but $y_{fi}(p_1, \dots, p_n, x_{h1}, \dots, x_{hn})$.

In order to solve for general equilibrium, using the simpler but erroneous expressions for consumer and firm demand, GE theory had to make a number of assumptions that all but removed any resemblance to reality. *This suggests that using correct but far more complex expressions for consumer and firm demand would make the system of equations unamenable to a solution.* This, of course is a typical problem with formalism as a constraint on how an economy is conceived, and continues to be a generalisable problem for many aspects of mainstream economics.

The fact that the consumer demand for a commodity is only a weak function of the output of other commodities means that it is only in the aggregate, and during recessions, that such effects are felt. And, as noted earlier, the effect of a fall in aggregate demand is first felt in the largest market of all, the labour market.

It must be here pointed out that the assumption that firms' profits are paid out to consumers *does not* integrate production and consumption. What matters is not profit but the amount paid out as income. In other words, what matters is not

$$\sum_{f} \sum_{i=1}^{n} p_i y_{fi} \tag{16}$$

where outputs are positive and inputs are negative, but the same quantity with no negative signs attached to inputs.

As a final issue, it seems worth emphasizing one of Keynes important insights that provides a useful contrast.[1] Keynes recognized that it was possible to solve this problem of inputs in the aggregate using income as an intermediate variable. A simple numerical example, with intertemporal substitution, using aggregate demand as the intermediating quantity, establishes this.

[1] In general it should be noted Keynes made a significant break with Marshall in so far as investment affects income paid out, in turn this affects consumption which affects revenues of firms, and so on…

Consider a simple, closed economy operating at full employment. It produces $90 worth of consumption goods. An equal amount is therefore paid out in income flows: wages, rent, interest, profit and so on. The saving rate is 10%, so $9 of these income flows is saved and $81 is spent on consumption goods. That means $9 worth of consumption goods is unsold. But then the economy also produces $10 worth of investment goods. An equal amount is therefore paid out as income. Since the saving rate is 10%, $1 of this is saved and $9 spent on consumption goods. Financial institutions of course turn the $10 saving into loans for investment. So all consumption goods are sold and savings are sufficient to pay for investment goods as in the table below.

	Consumption goods	**Investment goods**
Income	$90	$10
Consumption	$81	$9
Saving	$9	$1

Assume also that individuals have, on average, accumulated 20 years' worth of saving, which at present is valued at $200. Then thanks to a housing and stock market crash, an average of ten years' worth of accumulated saving is lost. This is not an outlandish figure; in the 2008 housing and stock market crash the median US household lost 18 years of real net worth (Federal Reserve, 2012) In an attempt to recover the lost net worth, households increase their saving rate from 10% to 15%. At this rate, they reckon they would take 20 years to recover their lost net worth. As a result of the higher saving rate, the money spent on consumption goods falls from $90 to $85. When manufacturers of consumption goods see their output remaining unsold they cut production to $85 and also cut purchases of investment goods to $8. Manufacturers of investment goods then cut production to $8. So total income now paid out is $93, a fall from $100 earlier. The economy now looks as in the table below.

	Consumption goods	**Investment goods**
Income	$85	$8
Consumption	$72.25	$6.8
Saving	$12.75	$1.2

Now total consumption is $79.05, so $5.95 worth of consumption goods remains unsold. As a result manufacturers of consumption goods cut their production further and curtail purchases of investment goods even more. The downward spiral continues unabated. It is of course possible to see that there is a damping factor. The saving in the first year is $13.95, so consumers might lower their saving rate a little as they begin to recover their lost net worth. But this must be balanced against the fact that consumers had expected a saving of $15, which did not materialize because the higher saving rate reduced the aggregate income. Whatever the details, the example illustrates the interconnection of production and

consumption, which Keynes of course recognized and which GE theory assumes out of existence.

If we refer back to the final extract from Arrow above it can be seen that the independence of production and consumption is a crucial assumption in proving profit maximization by firms and utility maximization by individuals. However, if the assumption is wrong, as we have shown it is, we can question both profit maximization and utility maximization. During a recession following a large asset market crash the minimization of consumption takes precedence over the maximization of utility. We suggest, therefore, that utility maximization is an idea applicable only to the special case of an economy in equilibrium, within a GE stylized mathematical construct (an extremely limiting situation and one in which aggregate demand is not falling). Similarly for firms during a recession, survival is more important than profit maximization.

Conclusion

In this short paper we have established that GE and Marshallian demand analysis are equivalent, and that GE theory is problematic in various ways. This has important implications for core Keynesian concepts, such as involuntary unemployment, as well as the continued relevance of his work. Furthermore, in so far as GE is the archetype of formalism, its limits demonstrate something about the limits of some uses of mathematics within the mainstream. This and other considerations regarding GE, are important for contemporary problems of New Classical Economics, DSGE and Real Business Cycle theory, though we do not discuss them in this paper.

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Author contact: philip.george@gmail.com

SUGGESTED CITATION:
Philip George, "The mathematical equivalence of Marshallian analysis and 'general equilibrium' theory", *real-world economics review*, issue no. 77, 10 December 2016, pp. 73-84,
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