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ON CLOSURE RULES, HOMOGENEITY AND DYNAMICS IN APPLIED GENERAL EQUILIBRIUM MODELS

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The problem of model 'closure' has been a major focus of the literature on the theoretical aspects of applied general equilibrium models. This paper addresses the issue by focusing on the implicit behavioral assumption leading to the existence of the closure problem. To do this, it uses a simple temporary equilibrium to make explicit the microeconomic behavior underlying these types of models. The closure problem is analyzed through the assumptions on the role of relative prices that it implies. In particular, emphasis is put on two mechanisms – the real balance effect and an expectation effect – in potentially ensuring the existence of an equilibrium. The paper concludes by showing the implications of this analysis for the construction of a theoretical framework for fully dynamic general equilibrium models.

1. Introduction

The identification of the 'closure' problem in general equilibrium models can be traced back to Sen (1963), who showed that the necessary ex-post equality between investment and savings could not be warranted if the following conditions were all to be satisfied: (i) full employment of labor, (ii) factors paid at their marginal productivity, (iii) household consumption as a function of real income only, and (iv) a fixed amount of investment. The choice of a 'closure rule' naturally follows from this impossibility and is the choice of a way to achieve equilibrium by relaxing one of the four constraints (such as allowing for unemployment in the 'Keynesian' closure).

Applied general equilibrium model builders have in effect always encountered this problem, either explicitly or implicitly, and a growing literature has

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been generated on the subject.[1] The focus of this literature has however essentially been on the question of which condition should be kept because best supported by empirical evidence or, conversely, of which was least justified in an applied model. The resulting conclusions have failed to generate consensus, but have clearly shown the importance of the issue, as the closure of a model determines its behavior and therefore is a key element to understand the lessons that can be drawn from it.

The aim of this note is to broaden the focus of the discussion by analyzing the foundations of the closure problem in light of the intertemporal decision-making process of economic agents. Such process is typically ill-developed in applied general equilibrium models. We reformulate it explicitly in a very simple temporary equilibrium framework which highlights the implicit assumptions underlying the closure debate. These concern, in particular, the absence of relations between financial assets or expectations and the real variables of the model. The validity of these assumptions is an empirical and not a theoretical issue, and should be discussed explicitly. If such assumptions are not found valid, however, new ways to resolve the closure problem are open. In addition, the construction of fully dynamic computable general equilibrium models in a consistent theoretical framework becomes possible.

The plan of the paper is as follows: section 2 summarizes the closure problem as usually formulated in the literature. Section 3 uses a temporary equilibrium method to explicitly derive agents' intertemporal optimizing behavior. A model specified on this basis is then presented in section 4, together with an analysis of its impact on the closure problem. Section 5 extends the discussion to a two-period model of the economy, while section 6 contains concluding comments.

2. The standard formalization of the problem

In order to present the standard approach of the literature to the problem of closure rules in computable general equilibrium (CGE) models, we use a very simple one-period model similar to those of Lysy (1982) and Rattso (1982), intended to be a one-sector version of large scale disaggregated CGE models.

The model includes one asset (used as store of value), labor, a consumption good (also used as capital good), a representative firm, and two representative households. It is presented for a closed economy, but can easily be extended to include the rest of the world.

The firm maximizes its profit, entirely distributed to households. Its technology is a two-factor neoclassical production function with constant

[1]See, for instance, Bourguignon, Michel and Miqueu (1983), Taylor and Lysy (1979), Lysy (1982), Robinson (1983) and Shoven and Whalley (1984).

returns to scale. The capital stock is fixed in the short run. Since all profits are distributed, investment is entirely financed by household savings. Its volume is exogenous. Households have constant average propensities to consume out of their incomes, with a lower propensity for profits than for wages. The government finances its exogenous public consumption by increasing the supply of the asset and (for simplicity) does not levy any taxes.

This model can be summarized by the following equations where two markets only – labor and good – have been made explicit (by Walras' law, we can neglect the third market, for the asset):

Good supply:	$Y=F(\bar{K},L^d)$,	(1)
Labor demand:	$F_L(\bar{K},L^d)=w/p$,	(2)
Exogenous investment:	$I=\bar{I}$,	(3)
Consumption function:	$C=c_L(w/p)L+c_\pi(\pi/p)$,	(4)
Labor supply:	$L^S=\bar{L}$,	(5)
Goods market equilibrium:	$Y=C+I+\bar{G}$,	(6)
Labor market equilibrium:	$L^S=L^d$,	(7)

where w and p are the wage rate and goods price; C, G, I and Y are, respectively, the volumes of private consumption, public expenditure, investment and production; K is the capital stock and F the production function; L^S and L^d are labor supply (exogenous at level $\bar{L}$) and demand; and, finally, c_L and c_π are the marginal propensities to consume out of wages (wL) and profits (π).

By rearrangement and substitution, it is possible to reduce the system (1)–(7) to the following equivalent form:[2]

$$\bar{L}=L^d(w/p), \tag{8}$$

$$F(\bar{L},\bar{K})=C(w/p)+\bar{I}+\bar{G}. \tag{9}$$

The closure problem appears very clearly in this summary form of the model: eqs. (8) and (9) are homogeneous in p and w, and only one variable, w/p, is therefore left to realize the equilibrium on two independent markets.

[2]To check the dependence of C in (9) on w/p only, just recall that at full employment Y is given and thus π/p depends on w/p only.

In other words, the system is overdetermined and one of the constraints of the model must be relaxed in order to find a solution.[3] Choosing a particular 'closure rule' means precisely deciding which constraint should be dropped.

Lysy (1982) considers four types of closure rules, which summarize accurately the debate among modelers:

(a) The 'Keynesian'[4] closure allows for underemployment of the labor force. In terms of the model, this means dropping eq. (5) and replacing $\bar{L}$ by L, which becomes endogenous in system (8)–(9).
(b) The 'Kaldorian' closure breaks the wage–marginal labor productivity link. Eq. (8) is then replaced by $F_L(K,L)\geqq w/p$ and $L\leqq\bar{L}$, and the system is solved for endogenous w/p and L. (It is typically used in a full-employment setting, with $w/p<F_L$ and $L=\bar{L}$.)
(c) The 'Johansen' closure assumes away eq. (4) and considers full employment equilibrium to be realized through residual adjustment of private consumption, C, in system (8)–(9).[5]
(d) The 'Classical' closure can be viewed as a system with endogenous investment. Eqs. (8)–(9) are then solved for w/p and I. Equivalently, this closure can be implemented by the addition of a new variable (the interest rate) entering consumption and investment schemes. In this latter case, (8)–(9) would solve for w/p and r.

In fact, once the assumptions leading to the system (8)–(9) have been accepted, there is no clear-cut theoretical justification for the choice of a particular closure except the modeler's 'general view of the world' and, not surprisingly, there is no agreement on this choice among modelers. More neoclassically-oriented economists choose, for instance, the classical closure [e.g., Dervis, de Melo and Robinson (1982) and Ballard et al. (1985)] whereas 'structuralists' tend to choose the Keynesian option. Such a choice is crucial to the models. It has been shown to have important theoretical[6] as well as empirical[7] consequences, which affect significantly both the structure of the models and their policy conclusions.

It is important to note that the closure problem arises in model (8)–(9) because of the *dynamic* nature of the economy, reflected in the possibility for the agents to save or dissave. If the time horizon of all agents was only one period, there would be no saving, investment or government deficit, and eq.

[3]Several complexities are typically added to the system (8)–(9) in CGE models: a labor supply which depends on the real wage, investment as a function of the current marginal productivity of capital (and thus ultimately on the real wage) and government tax rates on consumption or incomes. This would not, however, change the fundamental overdeterminacy of the model.

[4]For the semantics of the closure terminology, see Lysy (1982).

[5]Alternatively, one could assume that the government pursues an active expenditure policy in order to maintain full employment of the labor force. G would then become endogenous in (8)–(9).

[6]See Bell (1979), Bruno (1979) and Taylor and Lysy (1979).

[7]See Rattso (1982).

(9) would be an identity. In addition, there would be no need for a store of value, and thus only two markets would exist, instead of three. In such a case, equilibrium on the labor market would imply automatically equilibrium on the goods market, by Walras' law.

Therefore, in order to analyze the foundations of the closure problem, we look, in section 3, at the microeconomic intertemporal decision-making process.

3. Intertemporal decision-making

The microfoundations of the production and consumption allocation decisions (in a multi-sectoral framework) based on static profit and utility maximization by firms and households, as implicitly done in model (1)–(7), are quite standard and well accepted. Such a framework of analysis is, however, not extended to the intertemporal side of agents' optimizing behavior, since investment is specified exogenously, and fixed proportions out of income are used for savings.

We analyze the microfoundations of intertemporal decision-making in a temporary competitive equilibrium context with money. This framework assumes the absence of a complete set of future markets. Because of the impossibility of contracting on some future markets, agents' expectations of the future (which influence their current behavior) are not necessarily consistent with one another.

This framework is chosen on grounds of realism: the Arrow–Debreu assumption of a complete set of future markets is clearly not met in reality. Moreover, such a framework can be derived naturally as an extension of model (1)–(7). We suggest in section 5 how the analysis can easily be adapted to an Arrow–Debreu framework, or a temporary equilibrium framework without money.

The particular model we retain is a very simple two-period one, adapted from Grandmont (1983). It includes three goods in each period: a consumption good, labor and money (which is the store of value). Markets are supposed to exist for the current period only, and there is therefore no room for future contracts. Money is the only store of value available in the economy (there is no equity market) and it yields a zero nominal interest.[8] In this section, we derive agents' optimal behavior, while the full model is presented in section 4.

3.1. Households

Consider a representative consumer who lives only two periods, and does

[8]This assumption allows us to abstract from portfolio-choice considerations, which do not affect the substance of our discussion.

not work in the second one.[9] His intertemporal utility function depends only on the volume of consumption in each period. Money is taken as a numeraire in each period. As in the preceding model, we add to these simplifying assumptions a fixed labor supply.[10]

The program of the household at period one is thus

$$\max U(C_1, C_2), \quad \text{s.t.}$$

$$p_1 C_1 + M_1 = M_0 + w_1 \bar{L} + \pi_1, \tag{10}$$

$$p_2^e C_2 = M_1, \tag{11}$$

where w_1, p_1 and π_1 are, respectively, the wage rate, the price and the amount of profit of period one; C_i and M_{i-1} are, respectively, the consumption level of period i and money holding at the beginning of period i; and p_2^e is the price that the household expects to prevail in period 2.

We can use (11) to eliminate C_2 in the utility function. Once this is done, the first-order conditions of the problem (where λ denotes the Lagrange multiplier) are

$$\frac{\partial U}{\partial C_1} = \lambda p_1, \tag{12}$$

$$\frac{\partial U}{\partial (M_1/p_2^e)} = \lambda p_2^e, \tag{13}$$

$$C_1 + \frac{M_1}{p_2^e} \cdot \frac{p_2^e}{p_1} = \frac{M_0}{p_1} + \frac{w_1 \bar{L} + \pi_1}{p_1}. \tag{14}$$

This system can be inverted under standard conditions on $U(\cdot)$ to yield

$$C_1 = C_1\left(\frac{p_2^e}{p_1}, \frac{M_0}{p_1} + \frac{w_1 \bar{L} + \pi_1}{p_1}\right), \tag{15}$$

$$\frac{M_1}{p_2^e} = \left(\frac{p_2^e}{p_1}, \frac{M_0}{p_1} + \frac{w_1 \bar{L} + \pi_1}{p_1}\right). \tag{16}$$

[9]It would be easy to make the model more realistic by introducing overlapping generations or more than two periods. However, although this would make the algebra significantly heavier, it would not change the substance and, in particular, the dependence of current equilibrium on the expectations of future prices would remain of the same nature.

[10]As before, endogenizing the labor supply decision would only complicate the algebra, without changing the results.

Suppose now, as in the preceding model, that there are two categories of households with specific preferences: workers, who receive only wages, and capitalists, who receive only profits.[11] To derive the consumption demand of workers, it suffices to drop π_1 in (15). It will depend only on the real wage rate w_1/p_1, the real value of wealth M_0/p_1 and the expected rate of inflation $i^e = p_2^e/p_1 - 1$. Similarly, the consumption function of capitalists is derived by dropping $w_1\bar{L}$ in (15). Noting that, at full employment, π_1/p_1 depends only on w_1/p_1, total consumption is then a function of w_1/p_1, M_0/p_1 and i^e. It is therefore possible to write the overall consumption function (where the subscript 1, for the current period, has been dropped), which replaces eq. (4),

$$C = C(w/p, M_0/p, i^e). \tag{15'}$$

By comparison with (4), it makes consumption depend explicitly on expectations and on real wealth (including its distribution across households). This will in general modify the nature of the closure problem.

3.2. Firms

The model in section 2 assumed exogenously fixed investment and no inventories. Allowing for endogenous inventories and fixed investment is not difficult. Neoclassical profit maximization will make them depend on present and expected prices and wages. For simplicity, we will endogenize only fixed investment, keeping the assumption of no inventories. Firms will invest up to the point where the cost of additional investment just equals marginal productivity. Assuming for simplicity that investment goods last only during the next period, the equilibrium condition is thus

$$p_1 = p_2^e \cdot F_K(\bar{L}, \bar{I}),$$

or

$$I = I(i^{e\prime}), \tag{17}$$

where $i^{e\prime}$ is firms' expected rate of inflation. Note that (17) equates the net real marginal productivity of capital to the real rate of interest (since money bears zero nominal interest rate).

Eqs. (15′) and (17) can be used to build a modified version of model (8)–(9).

[11]In our simple framework, capitalists own non-transferable property rights over firms, while their saving decision concerns money (as indicated before, adding portfolio-choice decisions would not affect the substance of the discussion).

4. Reformulation of the closure problem

It is now possible to write the equilibrium conditions of the model on the grounds of the preceding section (once again, we can concentrate on two markets only, given Walras' law),

$$\bar{L} = L^d(w/p), \tag{18}$$

$$F(\bar{L}, \bar{K}) = C(w/p, M_0/p, i^e) + \bar{G} + I(i^{e'}). \tag{19}$$

Households' and firms' expectations (i^e and $i^{e'}$) may depend on all current variables of the model, and in particular on p. As in model (8)–(9), this set of equations yields the relative price structure, i.e., the wage and current price levels relative to the price of money, which has implicitly been set to one.

Here, however, the system has in general a solution in w and p since it is not – contrary to system (8)–(9) – a set of two equations with only one equilibrating variable (w/p). Indeed, the two models differ fundamentally as to their homogeneity. The model summarized by (18)–(19) is homogeneous of degree zero in *all* prices, i.e., the wage, the current good price, the expected good price *and* the price of money (or, equivalently, the money stock if the price of money is given). Therefore, changing by the same factor the nominal wage and the current price of the good does not leave the variables of the model unchanged: both w and p are endogenously determined in the model. On the contrary, due to the particular form of its investment, consumption and savings functions, the model of section 2 is homogeneous in wages and current goods price (which are a *subset* of all prices of the model), regardless of the value of the money stock and of inflationary expectations.

Thus, the introduction of an explicit intertemporal optimization framework brings into the model two elements which, in general, *guarantee that an equilibrium exists*. The first one is the *real balance effect*, through which a change in the current relative prices of goods and money (i.e., p) affects the consumption/savings allocation. The second one is an *expectation effect* which makes the current equilibrium depend on the expected rate of inflation.

It should be emphasized that the existence of an equilibrium in model (18)–(19) does not depend on money illusion, as all agents are sensitive only to relative prices, present and future. Furthermore, the model is compatible with *neutrality* of money: starting from an equilibrium position, an instantaneous change in the level of money holdings by households[12] will leave real variables unchanged, implying only a simultaneous proportional change in p,

[12]Assume here a 'helicopter drop' of money, rather than an increase in money supply due to higher government spending, which would obviously change the real structure of aggregate demand.

if agents' inflationary expectations do not change.[13] But, contrary to (8)–(9) this model shows no *dichotomy* as the price level p is determined by the real sector of the economy (given the level of nominal money holdings) and does not have to be fixed exogenously as in usual CGE models.

For system (18)–(19) to be equivalent to the model in section 2, investment needs to be constant and consumer behavior needs to depend solely on the current real wage. This would require:

(a) the absence of the real wealth effect (or $M_0=0$), and
(b) unitary elasticities of price expectations with respect to current prices (i.e., $p^e=k\cdot p$, with k independent of p) for households and firms.

These two assumptions are in fact implicit in model (1)–(7) and in most applied general equilibrium models. In our view their validity should be discussed explicitly by modelers, since it is mainly an empirical question: the homogeneity property of model (1)–(7) does not result from the absence of money illusion (a natural assumption), but is *a statement about which relative prices matter and which do not*. It is quite possible that in some circumstances (a) and (b) are empirically valid, in which case the standard presentation of the closure problem provides all the possible resolutions of the overdetermination.

However, (a) and (b) are not necessarily true. A debate has in fact been active in macroeconomic theory on this subject for decades [see, for example, Tobin (1980) for a summary of several arguments]. This is particularly important for the closure discussion, since, if (a) and/or (b) are dropped, the overdeterminacy disappears. Dropping them can be viewed either as a solution to the closure problem, or as an extension of the available set of closure rules, through the introduction of wealth and expectation effects. However, allowing for real balance and expectation effects has more implication than just offering a 'new' solution to the closure problem. As shown in the next section, they are necessary to the construction of a consistent framework for fully dynamic models, an undertaking which is not possible when starting from model (1)–(7).

5. Dynamics in applied general equilibrium models

Multi-period CGE models of the type described by Dervis, de Melo and Robinson (1982) or surveyed by Shoven and Whalley (1984) are typically a *sequence of static one-period solutions*. This is in keeping with assumption (b) of section 4, which implies that intertemporal relative prices do not affect agents' behavior. In effect, it is possible to represent such models as a simple

[13]*Superneutrality* will not hold, however: a change in the rate of growth of money supply will typically alter inflationary expectations.

extension of model (1)–(7) to a two-period framework, as follows:[14]

$$F(\bar{L}_1, \bar{K}_1) = C(w_1/p_1) + \bar{G}_1 + \bar{I}_1, \tag{20}$$

$$F(\bar{L}_2, \bar{K}_2) = C(w_2/p_2) + \bar{G}_2 + \bar{I}_2, \tag{21}$$

where $\bar{K}_2$ is updated using $\bar{K}_1$ and $\bar{I}_1$. Except for this relationship on capital stocks, eqs. (20) and (21) are similar to eq. (9). As a result, the closure problem arises, in such models, in each period and is formulated in the same terms as in section 2.

The dynamics contained in model (20)–(21) is, however, very poor since expectations on future periods are not allowed to feed back into the current equilibrium. This obviously unrealistic framework is, fundamentally, due to assumption (b) which sets inflationary expectations exogenously and independently of all current economic variables. Hence, assuming (b) away not only offers a solution to the closure dilemma but also allows the *construction of fully dynamic models*, where the equilibrium of each period depends both on current stock variables and on expectations of future states of the economy. In the remainder of this section, we illustrate this with two simple examples.

The temporary equilibrium framework used in the previous section offers a first context in which it is possible to construct a dynamic model with a consistent underlying optimizing behavior of the agents. By extension of the model in section 4 (and, again, leaving aside the labor market equilibrium condition), such a model can be written[15]

$$F(\bar{L}_1, \bar{K}_1) = C_1(w_1/p_1, M_0/p_1, p_2^e/p_1) + \bar{G}_1 + I_1(p_2^{e'}/p_1), \tag{22}$$

$$F(\bar{L}_2, \bar{K}_2) = C_2(w_2/p_2, M_1/p_2, p_3^e/p_2) + \bar{G}_2 + I_2(p_3^{e'}/p_2), \tag{23}$$

where price expectations depend on past and current variables of the model.

The equilibrium of model (22)–(23) is found by specifying expectation functions (possibly assuming perfect foresight, and viewing period 2 as a long run equilibrium) and by solving simultaneously for both periods. In this solution, the *closure problem does not arise* because, while w_1/p_1 and w_2/p_2 are determined by the (omitted) labor market equilibrium conditions, p_1 and p_2 are determined by (22) and (23). These two prices (price of good relative to money in each period) affect the real equilibrium individually, through the real balance effect, but also as a ratio, through the expectation effect.

[14]Combining the equations as in (8)–(9) and leaving aside the labor market equilibrium conditions, which determines real wage in each period.

[15]Typically, the behavior of the model would be studied by introducing unexpected shocks and by analyzing deviations from the perfect foresight benchmark.

In the second example, we consider a non-monetary economy in order to underline the fact that the introduction of full dynamics or the solution of the closure problem are not linked with the real balance assumption. Rather, it is the relevance or irrelevance of the intertemporal price structure which is crucial. We assume an Arrow–Debreu economy (thus with a complete set of market at date 1) which lasts only two periods,[16] but has otherwise the same characteristics as the model above (production technology, etc.). As the economy lasts only two periods, there is no investment in period 2 and the model can be written

$$F(\bar{L}_1, \bar{K}_1) = C(w_1/p_1, p_2/p_1) + I(p_2/p_1) + \bar{G}_1, \tag{24}$$

$$F(\bar{L}_2, \bar{K}_2) = C_2. \tag{25}$$

Although there is no role for money in such an economy, there is no closure problem either since all relative prices serve as equilibrating prices: the real wage in both periods (full employment condition) and the relative prices of current and future goods. Again, this is due to the introduction of non-exogenously set inflationary expectations.

6. Concluding remarks

In this paper, we showed that the closure problem, as it is formulated in the literature on applied general equilibrium models, is in fact the logical consequence of specific implicit assumptions about the irrelevance of some relative prices on agents' behavior. Specifically, we indicated that, in a consistent intertemporal framework, the closure problem can only arise when real balance effects are ruled out and when agents' expectations are supposed to be unitary elastic. Both assumptions are the object of debates in economic theory and go beyond the field of applied models.

This implies that the homogeneity postulate of CGE models has to be discussed explicitly. The link between the overall price level and real variables cannot be assumed away without careful justification. If such a link turns out to be empirically insignificant, then the closure problem has to be faced in the terms described in section 2. Otherwise, the introduction of wealth and expectation effects provides a resolution of the problem. It also allows the modeler to build a fully dynamic model. Of course, this also creates new implementation problems in the specification of financial relationships and the determination of expectations. These are, however, not insurmountable

[16]The finite horizon assumption is only made here for simplicity. As shown in Summers (1981) or in the work of Auerbach and Kotlikoff, reviewed by Kotlikoff (1984), infinite horizon CGE models with perfect foresight and no money do not, either, run into the closure problem (which is, in fact, not mentioned as such by these authors who do not come from the 'CGE tradition').

as shown by the work of Summers (1981) and Kotlikoff (1984) on dynamics, or by the pioneering CGE model of Korea developed by Adelman and Robinson (1978), which integrates financial variables.[17] It is therefore possible to build models which incorporate wealth or expectation effects, when assuming them away is not empirically reasonable. At the same time, both the focus of CGE models and the range of problems they can analyze are expanded.

[17]As stressed by the authors, this model is very much in the temporary equilibrium spirit, even if it is not explicitly formulated in an intertemporal optimization framework, since financial assets (money and credit) are explicitly introduced (as well as myopic expectations). Like in model (18)–(19), the closure problem as defined in section 2 is thus avoided. (Note that money is moreover assumed to be non-neutral in their model, through the specification of money demands and through real effects of unanticipated changes in the stock of money on investment.)

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