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Identifying Causal Relationships from Policy Instruments to Target Variables

Abstract:

Can causal relationships between macroeconomic variables be identified using econometric methods? Only partly, we argue. Normally causal relationships cannot be identified from empirical analysis. However, if enough changes in policy rules have occurred during the observation period, it can be possible to identify causal relationships form policy instruments to target variables. An estimation procedure for obtaining this is sketched. This estimation procedure makes it possible to distinguish between causal effects of expected policy changes on one hand and (unexpected) shocks on the other.

Keywords: Methodology, causality, autonomous relationships, Lucas' critique, reduced rank regression.

JEL classification: B41, C32.

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Introduction

> Lucy: "I've just come up with a perfect theory. It's my theory that Beethoven would have written even better music if he had been married."
> Schroeder: "What's so perfect about that theory?"
> Lucy: "It can't be proved one way or the other!"
> Charles Schulz in "Peanuts" (1976)

There have been many important contributions on identification of causal relationships using econometrics. Ragnar Frisch and Trygve Haavelmo focused on autonomy in econometric relations.[1] Herbert Simon contributed further to the theory of casual order in systems of simultaneous linear equations. Robert E. Lucas illustrated that estimated relationships might be of no value in guiding policy, known as the Lucas' critique. David Hendry and his co-authors have contributed in developing tests for the Lucas' critique. Other contributors are Hermann Wold, Christopher A. Sims and Clive W. J. Granger. Recently, Hans Martin Krolzig and Juan Toro have applied reduced rank regression technique to identify causal relationships in econometrics, which may be a basis for a new approach in this field.

In many natural sciences, such as medicine, we can use controlled experiments to establish casual relationships. In macroeconomics we seldom can make use of controlled experiments. If we could, it would be simple to identify the causal relationship from the variable we control to the variable affected by the experiment. However, in lack of controlled experiments we have to interpret causal relationships form natural experiments. This can be very difficult and often impossible.

Causality is asymmetric; we can say that rain causes John to wear his raincoat, however, to say that John wearing his raincoat causes rain is absurd. The casual relationship goes form "rain" to "John wearing his raincoat" and not the other way around.

Cause precedes effect in time. Therefore, the ordering in time between cause and effect can be used to identify the causal relationship. Here, however, we will stress the asymmetry between cause and effect. Therefore, we will simplify by focusing on static relationships between variables. The type of causality we are investigating can therefore be labelled 'contemporary causality'.[2]

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[1] A relationship is said to be autonomous if it is unchanged when other parts of the system are changed.

[2] Since we are interested in 'contemporary causality' we will not discuss Granger causality, see Granger (1969). A variable A is said to Granger cause B if values of A up till time *t*-1 can help predicting B at time *t*.

In this paper we will argue for a new approach for identifying and testing causality. First, we will only identify causality from policy-controlled instruments to target variables. Causal relationship between target variables are normally impossible to identify, and not necessary to conduct policy analysis or forecasting. Second, the method distinguishes between unexpected (shocks) and expected (permanent) changes in policy. We should generally not expect changes of policy to have the same effect as a shock in the policy variable, cf. the Lucas' critique. However, the proposed estimation technique makes it possibly to test whether unintentional shocks have the same causal effect on the target variable as intentional policy changes have. To prevent the paper to be too technical we only sketch the estimation procedure in the paper and preset a more detailed version in the appendix.

Causality and philosophy

> If we reason *a priori*, anything may appear able to produce anything. The falling of a pebble may, for aught we know, extinguish the sun; or the wish of a man control the planets in their orbits. It is only experience, which teaches us the nature and bounds of cause and effect, and enables us to infer the existence of one object from that of another.
>
> David Hume (1711-1776) in
> "An Enquiry Concerning Human Understanding (1748)

Empiricism and David Hume

A natural starting point in a presentation of philosophy, causality and macroeconomics is David Hume (1711-1776). Hume was not the first philosopher discussing causality. (For example Aristotle (384-322 BC) was interested in causality.) However, being a central figure of the philosophical school of British empiricism and the author of the definitive eighteenth-century statement of the quantity theory of money, he stands at the headwaters of all modern discussion of both causality and macroeconomics.

Hume denied that we could draw sure knowledge from observations. Even if we observe that the sun has risen every morning until now we cannot be sure that it will raise tomorrow. This is known as the 'Humean scepticism'. Does this mean that Hume did refute casual statement since they are impossible to prove? No, Hume believed that the sun would rise the next day. Casual statements are based on observations. These cannot be verified, but we can believe in them until they are falsified.

In Humes famous example from billiard he divides the idea of one billiard ball striking another and causes it to move into three elements: First the cause is spatially contiguous with the effect. Second, the cause precedes the effect. Third, the cause is necessarily connected to the effect.

Hume put forward many causal hypotheses in economics. Hume (1752) presents the *quantity theory of money*, which states that the stock of money relative to the stock of goods causes prices. Other casual statements are the *specie-flow mechanism* (prices causes money); *loanable funds doctrine* (supply and demand for loans causes interest rate); *arbitrage doctrine* (the interest rate causes profits and profits causes interest rate); and the *sociological doctrine* ("manners and customs of people" causes production, profits and loans), see Hoover (2001).

Hume does therefore not confuse cause with correlation (empirical regularities). According to the causal statements in Hume (1752), interest rates and money are correlated. However, there is no direct casual effect between them; neither does interest rate cause money nor does money cause interest rate. They are correlated because they are caused by the same source, which is "manners and customs of people".

Idealism and realism

According to the empiricist all ideas are derived form experience; therefore knowledge of the physical world can be nothing more than a generalisation from particular instances and can never reach more than a high degree of probability. Empiricists tend to base causal statements upon empirical regularities only.

Modern idealism can be seen as a 'synthesis' between rationalism (reason will lead us to the truth) and empiricism (knowledge is derived from experiences).[3] In order to make sense of experiences we have to apply reason. The same observation can be interpreted in different ways, depending on the assumptions. Therefore empirical observations are necessary but not sufficient for establishing causal laws. The empirical regularities must also make sense within the existing body of conceptual knowledge through which we interpret our (perceptions and) experiences in order to treat them as causal relationships.

In economics both the Austrian economists (Carl Menger, Ludwig von Mises, Friedrich A. von Hayek, etc.) and the new classical economists (such as Robert E. Lucas) can be classified as idealists. Idealistic economists see macroeconomics as redundant because the relationships between aggregates are no less than the sum of individual behaviour. They also advocate using *open systems*, since the world is too complex to generate general knowledge by studying closed systems (i.e. ignoring parts of the economy).

According to critical realism the real world exists independent of our consciousness, and our understanding of the real world must be corrected and interpreted. Many causal mechanisms can work at the same time, and if they work in different directions the variable caused by these mechanisms may not change. Causal mechanism may therefore work even if they cannot be observed empirically.

New Keynesian macroeconomists have been characterised as critical realists, see e.g. Dow (1990) and Lawson (1994). Their goal is to increase the understanding of the causal structures underlying real processes. To achieve this they sought to give Keynesian economics microeconomic foundations, where they include asymmetric information, price rigidities, monopolistic competition, and introduces rational expectations in some markets.

[3] Immanuel Kant (1724-1804) established a compromise position between rationalism and empiricism, see Kant (1781). Kant argues that we need reason to make sense of our experiences and observations in order to employ our capacity for rational thought.

Causal structure

We can have causality in a probabilistic sense. A medicine, for example, can increase the probability of curing a disease. The use of the medicine does not (necessary) cause the patient to be cured, but it causes the probability that the patient is cured to increase. In notation we can write

(1) $$P(cured \mid medicine) > P(cured),$$

which states that the probability that a sick person getting cured when taking the medicine is higher than for an arbitrarily chosen sick person (i.e. a person we do not know is taking the medicine or not). By applying Bayes' theorem,[4] we can rearrange (1) to

(2) $$P(medicine \mid cured) > P(medicine).$$

The inequality expression in (2) indicates the opposite causal direction; form cure to medicine. In this example it is easy to reject the causal direction in (2) and to accept (1). It is also easy to test the causal relationship in (1) by using a controlled experiment: Give some sick persons the medicine and the other a placebo, and see if there is a higher ratio of cured people among those who got the medicine.

Sometimes, however, there will not be an agreement in witch direction the causal relationship goes. In economics there is no agreement on whether money causes prices (as Hume's quantity theory of money claims) or if prices causes money.

Another problem is that there need not be any casual relationship between two variables even though they are correlated. There may be a common cause driving the two variables. We saw an example of this in the first subsection, where the correlation between interest rates and money occurs - according to Hume - because "manners and customs of people" causes both interest rate and money.

There may also be a causal relationship even if there is no correlation. If A is caused by both B and C, and C is a variable controlled by the government, then C can be adjusted to compensate changes in B such that there is no fluctuation in A. In the macro model IS-LM both a real "shock" (B) and the money stock (C) causes interest rate (A). If the central bank targets a level for the interest rate, it will react to a real shock by adjusting the money stock such that the interest rate becomes unchanged.[5]

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[4] Bayes' theorem: $P(A|B)=P(B|A)\bullet P(A)/P(B)$.

[5] This example is taken from Hoover (2000). Some will disagree with this example and argue that the policy variable the central bank has control of is the interest rate (through their deposit and folio rates). Then this is not an example of two variables B and C causing A in different directions such that A is unaltered. Instead, the real shock (B) causes money (A).

Finally, correlations may also be non-sense or spurious. The first occurs if some variables are correlated, even though they have nothing to do with each other neither directly nor indirectly. A positive correlation of storks and newborn babies is an example of a non-sense correlation (that is if you do not believe in fairy tails).[6]

Spurious correlation can be an important problem in macroeconomics if not taken seriously. Many times series grow over time, and we say they follow a (stochastic) trend. They will therefore probably be correlated, even though they may not be related in any sense.

Controllability

The problem of causality can be illustrated in a small equation system. Let *y* and *z* be variables, and α_i and β_i be parameters (i=0,1).

(3) $$y = \alpha_0 + \alpha_1 z$$

(4) $$z = \beta_0 + \beta_1 y$$

The problem with the equation system in (3) and (4) is that it is over-parameterised; we have two equations to solve for four coefficients. There is therefore an infinite set of parameter values in (3) and (4) that will lead to the same values of the variables. This is an example of the identification problem. Any causal relationship from *z* to *y* (or the other way around) can be claimed to exist between the variables, but we are in no position to falsify the claim.[7] This can lead us to question if causal claims has any meaning in this example? And if causal claims are meaningful, do they describe anything about the real world or do they only function as a way for us to interpret the world? If the latter is true, it will imply that the causal understanding is subjective and can differ from person to person.

Now let *z* be a policy instrument and *y* be a target variable. We then want to know what happens to the target variable if the policy instrument is changed. Therefore the causal relationship goes form *z* to *y*, and not the other way. This involves restricting $\beta_1 = 0$. But if we introduce the restriction $\beta_1 = 0$ the system is still over-parameterised. However, following Simon (1952,1953), assume that the policy

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[6] Sober (1988, p. 90) gives an example familiar to philosophers of correlation between bread prices in England and the sea level in Venice. Hendry (1980, pp. 17-20) gives an example more familiar to economists of the correlation between prices and accumulated rainfall in Scotland.

[7] Therefore, according to Popper (1959), the claim is non-scientific or tautological. For a statement to be scientific if must be possible to falsify.

instrument z can be controlled (say, by the government) by changing the value of the coefficient β_0.[8] Then, if the coefficients in (3) remains unaltered when β_0 is changed, we can say that (3) represent the causal relationship from z to y. This implies that we define a causal relationship such that it represents a way of controlling y through z. Or alternatively; if z is altered, (3) gives us the new value of y. Therefore, if y is unaltered when β_0 (and therefore z) is changed, there is no causal relationship from z to y, and therefore $\alpha_1 = 0$. Similarly, if y increases when β_0 is increased, there is a positive causal relationship represented by $\alpha_1 > 0$.

It might be worth looking at the problem the other way around as well. Let

(3') $$y = a,$$

be the value of the target variable y before the government changes β_0. When β_0 is changed, a may change. For simplicity we assume that the relationship between β_0 and a is linear; $a = a_0 + a_1\beta_0$. Replacing a with this expression, and using $\beta_0 = y$ when $\beta_1 = 0$, yields

(3'') $$y = a_0 + a_1 z .$$

Therefore (3) represents the causal relationship if, and only if, $\alpha_0 = a_0$ and $\alpha_1 = a_1$.

[8] The idea of letting a parameter in a model be of direct control of the government might be new to an economist. Normally economists treat a variable as controlled by the government (and label that variable an exogenous variable.) In the system here this is equivalent, since being in direct control of the parameter implies being in direct control of the variable. However, later in the paper this distinction will be important.

Causality and macroeconomics

> The worst of him is that he is much more interested in getting on with the work than in spending time in deciding whether the job is worth getting on with. He so clearly prefers the mazes of arithmetic to the mazes of logic, that I must ask him to forgive the criticisms of one whose tastes in statistical theory have been, beginning many years ago, the other way around.
>
> John Maynard Keynes (1883-1946) in "Professor Tinberger's Method" (1939)

Causality in Macroeconomics

The idea of understanding causality as an indication of controllability makes it important for macroeconomics. If we can find the causal relationship from variables controlled by the government to other economic variables, we can understand how the other economic variables (also known as target variables) will change when the policy is changed. Identifying causal relationship is therefore necessary in order to understand how policy changes affect the economy.

However, to identify causal relationships between policy instruments and other variables, there must be some structural changes in (the marginal process of) the policy variables. Only when such structural shocks occur it is possibly to identify the causal effect of the policy changes on the target variables.

Tax and consumption

Now, let us turn to an economic example. We look at an economy where *Y* is income (before taxation), *C* is private consumption and *T* is total tax. Furthermore, let lower case letters denote that the variable is measured at a logarithmic scale, e.g. $y=\log(Y)$.

(5) $$c - y = \upsilon + \varepsilon_c$$

(6) $$t - y = \tau + \varepsilon_t$$

Here the epsilons are error terms with expectation zero. The parameter τ, which can be interpreted as the (log of the) tax rate, is the parameter controlled by the government. It is naturally to interpret the tax rate as reflecting the policy decision, since it is actually the tax system (here represented by the tax rate) that is decided by the government. The total tax that this tax rate yields is unknown to the government at the time they decide the tax rate, though they form expectation of the total tax, which is included in the state budget. [9]

In (5) and (6) the tax, *t*, is the policy instrument (i.e. the variable the government controls through the tax rate) and private consumption, *c*, is the target variable (i.e. the variable the government want to affect by changing its policy - here; the tax rate). If the tax tare τ is increased, the disposal income will decrease. Therefore, private consumption is expected to decrease. In the model above this will be reflected in a decrease in the parameter υ. Assume the relationship between these two parameters is represented by $\upsilon = \lambda_0 - \lambda_1 \tau$. Utilizing this relationship yields the following causal relationship form taxes to consumption;

(7) $$c - y = \lambda_0 - \lambda_1 (t - y) + u ,$$

where $u = \varepsilon_c + \lambda_1 \varepsilon_t$ is the error term. The parameter λ_1 quantifies the effect on the consumption (rate) by a change in the tax (rate).

Frisch and Haavelmo

Frisch (1938) introduces the concept of degree of autonomy for a relationship. This concept is similar to what we described under the subsection 'Controllability' in the previous section. Frisch argues that equation (3) does *not* state that when *z* has some arbitrary values we can compute *y* by (3). To assume that (3) should hold for any value of *z*, Frisch continues, would indeed imply that we conceived of the possibility of *another* structure than the one that prevailed when the equation (4) was determined. We therefore only can assume (3) to hold if (4) holds. However, (3") is constructed to hold for any value of *z* and would therefore be an autonomous relationship. In a larger system an equation will be said to have a high degree of autonomy if it remains unchanged when other important parts of the system are changed. Identifying autonomies systems are important, according to Frisch; "The higher this degree of autonomy, the more *fundamental* is the equation, the deeper insight which it gives us into the way in which the system functions, in short, the nearer it comes being a *real explanation*. Such relations form the essence of 'theory'." (p. 417.[10]) Furthermore; "If the results of the investigations are to be applied for economic political purposes - and *reforming* the existing economic organization - it is obviously autonomous structural relations we are interested in." (p. 418.)

[9] The government controls the policy instruments through the rule of how these variables are set. A change in the tax level is therefore not necessary due to a change in policy, since it can stem from a change in the production level. However, a change in the tax rate is a policy change. Confront also footnote 8.

[10] The page references refer to the reprint of the article in Hendry and Morgan (1995).

Frisch argues that experimentation (such as changing the value of β_1 in the subsection 'Controllability' in the previous section) can help us determine autonomous equations. Furthermore, Frisch suggests that interviews can sometimes be us a substitute for experimentation in order to identify causal statements. (p. 418.)

According to Haavelmo (1943,1944), identification of autonomous equations must be based on econometric theory.[11] The problem is therefore "*knowing something* about real phenomena, and of making realistic assumption about them. In trying to establish relations with high degree of autonomy we take into considerations various *changes* in the economic structure which might upset our relations, we try to dig down such relationships as actually might be expected to have a great degree of invariance with respect to certain changes in structure that are 'reasonable'." (Haavelmo, 1944, p. 29.)

However, Haavelmo recognizes the problem that relationships we believe are autonomous will depend on the theory we believe in. This seems to be the point where Frisch (1938) and Haavelmo (1944) have different views; Frisch wants to identify autonomous relationships to learn more about theory, whereas Haavelmo uses theory to identify autonomous relationships.

Equation (5) and (6) are not autonomous since a change in the tax rate will change the coefficients in those equations. Equation (7), on the other hand, is autonomous, since it will remain unaltered if the tax rate is changed. Equation (7) can therefore be used for policy analysis. As we see; what Frisch and Haavelmo describe as an autonomous relations seems to be the same as what we label a causal relation.

[11] Haavelmo (1944) synthesised the Cowles Commission approach with the Neyman-Pearson approach.

The Lucas critique

> [T]he question on whether a particular model is structural is an empirical, not a theoretical, one. If the macroeconometric models had complied a record of stability, particularly in the face of breaks in the stochastic behavior of the exogenous variables and disturbances, one would be skeptical as to the importance of prior theoretical objections of the sort we have raised.
>
> Robert E. Lucas and Thomas J. Sargent in "After Keynesian Macroeconomics" (1978/9)

Lucas' supply curve

Lucas (1976) argues that macroeconomic models cannot in general be used for policy analysis because the estimated relationships might not be invariant to the change of policy. This is now known as the Lucas' critique, even though it is highly related to the concept autonomous relationships described in Frisch (1938) and Haavelmo (1944).

To illustrate the Lucas' critique we present the Lucas' supply equation (or Lucas' supply curve).

(8) $$y_t = \bar{y} + \beta(p_t - E_{t-1}[p_t])$$

In equation (8) $E_{t-1}[p_t]$ is the expectation of the prices in period *t* formed in period *t*-1. Therefore, $p_t - E_{t-1}[p_t]$ is the expectation error of the prices in period *t*.

Equation (8) states that aggregate production will become high ($y_t > \bar{y}$) if prices are higher than expected. Suppose the government makes use of the following rule for the price level:[12]

(9) $$p_t = \bar{p} + \varepsilon_t$$

The rational expectation of the price will therefore be $E_{t-1}[p_t] = \bar{p}$, and imposing this in (8) yields

(8') $$y_t = \alpha + \beta p_t,\ \alpha = \bar{y} - \beta\bar{p}.$$

Equation (8') is known as the Phillips' curve, and implies a positive relationship between production and prices. If the economy were as described in equation (8) and (9) and an econometrician were to estimate the relationship between production and prices, he would estimate a relationship such as in

[12] We simplify here by analysing as if the price is the policy instrument and that $\bar{p}$ is the parameter the government controls. This is just a simplification; normally it is assumed that the government can control prices through the money stock.

(8'). However, the government cannot conduct a policy that will lead to a high production level if the agents in the economy form their expectations rationally. According to (8) only unexpected changes in the price will lead to changes in production. If the price change is expected it will not influence the production, since agents forms price expectations rationally.

The assumption of rational expectations is not essential for the Lucas critique. Agents might form their expectations by a rule of thumb, and might change this rule of thumb if the policy is changed. To be able to make policy analysis on a model the parameters of the model must be invariant to changes in the policy rule.

Lucas can be classified as an idealist. With the Lucas supply curve he shows that empirical regularities does not necessary imply causal relationship. This is in line with idealism, which sees empirical regularities as necessary but not sufficient for causal claims.

Testing for the Lucas' critique

As the above quote shows, Lucas' is of the opinion that the question of whether a model is structural or not is an empirical question.[13] The procedure used for testing the Lucas' critique today is found in Engle and Hendry (1993), and based upon Gordon (1976, pp. 48-49) and Hendry (1988). This testing procedure follows two steps:

1. Test for parameter constancy of both the conditional model and the marginal models. If the parameters in the structural model are stable, whereas the parameters in the marginal models are not, the Lucas' critique does not apply. (See above quote and Hendry, 1988.)

2. Develop the marginal model by including dummies[14] or other variables until its parameters are empirical stable. Then test for the significance of those dummies or other variables in the conditional model. Their insignificance in the conditional model demonstrates the invariance of the parameters in the conditional model by the modelled interventions. (See Engle and Hendry, 1993.)

[13] Structural relations in Lucas vocabulary are to a large degree the same as what we label 'causal relations'.

[14] A dummy is a constructed variable that (normally) takes the value 1 in some periods and 0 in other. The most normal dummies are impulse dummies (being 1 in one period and 0 otherwise) and step dummies (being 0 before a certain period and 1 thereafter).

We will now demonstrate how this testing procedure works in a simple probabilistic and static model with two variables. Let y be the target variable and z be the policy instrument. The system in its marginal form is

(10) $y_t = a_{y,t} + \varepsilon_{y,t}$,

(11) $z_t = a_{z,t} + \varepsilon_{z,t}$.

The government can control the instrument variable by changing $a_{z,t}$ (where the subscript t is included to capture the fact that this parameter may have different values at different times, t). If there is a (contemporary) casual relationship from z to y, $a_{y,t}$ must change when $a_{z,t}$ changes.[15]

Let σ_y^2 be the variance of $\varepsilon_{y,t}$; σ_z^2 the variance of $\varepsilon_{z,t}$; and σ_{yz} be the covariance between $\varepsilon_{y,t}$ and $\varepsilon_{z,t}$. Furthermore, let $\omega = \sigma_{yz}\left(\sigma_z^2\right)^{-1}$ and $u_t = \varepsilon_{y,t} - \omega\varepsilon_{z,t}$. Then the model of y conditioned on z becomes[16]

(12) $y_t = \left(\alpha_{y,t} - \omega\alpha_{z,t}\right) + \omega z_t + u_t$.

If the casual relationship from z to y corresponds to the correlation in their errors, $\alpha_{y,t} - \omega\alpha_{z,t} = constant = a$, and we can estimate the system

(12') $y_t = a + \omega z_t + u_t$.

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[15] More precisely, the system can be written with dummies. Let $a_{z,t} = \alpha_z + \sum_{i=1}^{k} \beta_{z,i} d_{i,t}$, where $d_{i,t} = 0$ if $t \le \tau_i$ and $d_{i,t} = 1$ if $t > \tau_i$, such that $a_{z,t} = \alpha_z + \sum_{i=1}^{j} \beta_{z,i}$ when $\tau_j < t \le \tau_{j+1}$ $(j=0,1,...k)$ $\tau_0 = 0, \tau_{k+1} = T$. This implies that the value of the parameter $a_{z,t}$ is changed at times $\tau_1, \tau_2, ..., \tau_k$.

If there is a casual relationship from z to y, $a_{y,t}$ must change when $a_{z,t}$ changes. Therefore, let $a_{y,t} = \alpha_y + \sum_{i=1}^{k} \beta_{y,i} d_{i,t}$. By using this, the marginal system can be written as

(10f) $y_t = \alpha_y + \sum_{i=1}^{k} \beta_{y,i} d_{i,t} + \varepsilon_{y,t}$,

(11f) $z_t = \alpha_z + \sum_{i=1}^{k} \beta_{z,i} d_{i,t} + \varepsilon_{z,t}$.

[16] Written with dummies, this relation becomes

(12f) $y_t = \left(\alpha_y - \omega\alpha_z\right) + \omega z_t + \sum_{i=1}^{k} \left(\beta_{y,i} - \omega\beta_{z,i}\right) d_{i,t} + u_t$.

If the casual relationship from z to y corresponds to the correlation in their errors, then $\beta_{y,i} - \omega\beta_{z,i} = 0$.

Testing criterion 1 implies estimating (12') and (11), and examine if the parameters a, ω and a_z are constant over time. If a and ω are constant, and a_z is not, then the Lucas' critique does not apply, according to this criterion.

Criterion 2 implies defining the stable marginal model (11) letting $a_{z,t}$ vary (i.e. with dummies), and estimating the conditional model letting $\alpha_{y,t} - \omega\alpha_{z,t}$ vary (i.e. with these dummies). This implies estimating (12) (or, more precisely; estimating (12f)). If the variation in $\alpha_{y,t} - \omega\alpha_{z,t}$ is insignificant (i.e. the dummies in (12f) are insignificant, implying $\beta_{y,i} - \omega\beta_{z,i} = 0$ at least approximately,) this demonstrates the invariance of the parameters in the conditional model by the modelled interventions (here represented by the dummies). Engle et al. (1983) define the policy instrument z as super-exogenous with respect to the parameters of interest (here; a and ω) if criteria 1 and 2 holds.

Testing the Lucas' critique on the Lucas' supply curve implies, according to the first criterion, to estimate the conditional model (8') and the marginal model (9). If there has been no changes in the policy, i.e. $\bar{p}$ is unchanged, the parameters in both the conditional model and the marginal model are constant and we cannot judge whether the Lucas' critique applies.

If there have been changes in the policy, the parameter $\bar{p}$ in the marginal model will not be constant over time. However, the parameter α in the conditional model will not be constant either, since $\alpha = \bar{y} - \beta\bar{p}$ where $\bar{y}$ remains unchanged when $\bar{p}$ changes. Therefore, the Lucas' critique applies to the conditional model (8').

If agents react differently when changes in the policy instrument variable is expected than when it is unexpected, the conditional model (such as in (8') and (12')) cannot be used for policy analysis. In the case of the Lucas' supply curve changes in prices only causes changes in production if the change in the price is unexpected. Therefore, the government cannot use the observed correlation between prices and output to increase output. The instrument is ineffective, even though there is a correlation between the instrument and the target.

Weaknesses with the test

There are two major weaknesses with the test of the Lucas' critique. First, since we apply the test on single equations instead of the whole system the test has a weak power. Second, since it is normal to perform a so-called general to specific approach before the Lucas' critique is tested one favours the (null) hypothesis that the Lucas' critique does not apply.[17]

Krolizig and Toro (2000) shows, by using a Monte Carlo experiment, that there is loss in power of the test by applying the testing procedure described above on single equations compared to a test on the system as a whole. The loss in power turns out to be more important in small samples (T=50, i.e. 50 observations of each variable) than in large samples (T=100 or T=150). Since small samples are often the case in macroeconomics, this is an important argument for applying system tests instead of single equation tests.

The second weakness is also important. The testing of the Lucas' critique is often conducted as a part of a general to specific (GETS) approach. This implies starting out with a general unrestricted model (GUM) when identifying the conditional model. The model is then simplified by imposing testable and accepted restrictions. Many criteria are used to determine if a restriction is accepted, such as explanatory power (e.g. likelihood value), diagnostic tests (absence of autocorrelation and non-normality) and parameter stability. By following the GETS approach one increases the probability that the conditional model will have constant parameters. Furthermore, when identifying the marginal model(s), the investigator often tries different formulations until (s)he finds one that is unstable. Due to this approach for identifying the conditional and the marginal models, criterion 1 in the testing of the Lucas' critique will imply that the Lucas' critique will not apply. Therefore, in almost all articles where the Lucas' critique is tested finds that the critique does not apply, see Ericsson and Irons (1995).

[17] An additional problem is that tests of cointegrating ranks are not valid if there are breaks in the marginal processes, conf. Harbo et. al (1998)

A 'new' testing approach

> The principal task of econometric theory is to establish such relations as might be expected to possess as high degree of autonomy as possible. [Nevertheless,] The construction of systems of autonomous relations is (…) a matter of intuition and factual knowledge; it is an art.
>
> Trygve Haavelmo (1911-1999) in "The Probability Approach in Econometrics" (1944)

Here we will only sketch the new approach. A more precise description of this new testing approach is described in the appendix. The testing procedure builds on Krolzig and Toro (2000). They apply it to test for super-exogeneity. We, however, apply it - with some adjustments of the procedure - to identify causal relationships where we allow unexpected (shocks) and (permanent) policy changes to have different effect on the target variables.

We return to the simple probabilistic and static model with two variables form the subsection 'Testing for the Lucas' critique'. The system in its marginal form is

(10) $$y_t = a_{y,t} + \varepsilon_{y,t} \,,$$

(11) $$z_t = a_{z,t} + \varepsilon_{z,t} \,,$$

where *y* is the target variable and *z* is the policy instrument. This 'new' test also follows two steps:

1. Test for parameter constancy in the marginal model of the policy instrument (i.e. (11)). If the parameters in the marginal model of the policy instrument are unstable there has been significant changes in the policy (which is necessary in order to identify the casual relationships).

2. Test if there exists a linear relationship between the marginal models (i.e. (10) and (11)) such that the linear relationships between the parameters are constant.

Here, criterion 1 implies testing if $a_{z,t}$ in (11) is constant. Criterion 2 implies testing if there exists such a λ that $a_{y,t} - \lambda\alpha_{z,t}$ is constant.[18] If $a_{z,t}$ changes value only once it is always possible to find a relationship such that $a_{y,t} - \lambda\alpha_{z,t}$ is constant. We have, therefore, not tested if this relationship will be constant.

[18] If $a_{y,t}$ is constant $a_{y,t}$-$\lambda a_{z,t}$ is constant if λ=0. Then (10) will represent the causal relationship from *z* to *y*, stating that *y* will not change by (expected) changes in *z* (conf. the Lucas' supply equation).

If $a_{z,t}$ changes value more than once, we can *test* if there is a linear combination of the two relationships that is constant. If the hypothesis that a linear combination of the two variables is constant is not rejected, the causal relationship can be written as

(13) $$y_t = \left(a_{y,t} - \lambda \alpha_{z,t}\right) + \lambda x_t + u_t ,$$

where $u_t = \varepsilon_{y,t} - \lambda \varepsilon_{z,t}$.

Furthermore, we can test if the parameters in (13) are super exogenous. This implies testing if $\lambda = \omega$, where is defined as $\omega = \sigma_{yz}\left(\sigma_z^2\right)^{-1}$ (i.e. as in the subsection 'Testing for the Lucas' critique'). If the parameters are super exogenous policy changes will have the same effect as policy shocks.

If there are not enough policy changes to identify the causal relationships from policy instruments to target variables, two other approaches can be used: (i) assume that expected and unexpected policy for some of the policy variables changes have the same effect (which cannot be tested since it is not enough information in the data); or (ii) use interviews as suggested by Frisch (1938).

Conclusions

> In spite of all the evidence that life is discontinuous, a valley of rifts, and that random chance plays a great part of our fates, we go on believing in the continuity of things, causation and meaning.
>
> Salmon Rushdie (1947-) in "The Ground beneath Her Feet", (1999)

To analyse policy changes we must know the causal relationships from the policy instruments to the target variables. However, such relationships can be difficult to identify. Only when the policy variables have been changed during the estimation period the causal relationships can be determined based upon the data alone.

Few econometricians use the term 'causal' when discussing methodological problems. Expressions that 'autonomous relationships' (e.g. Frisch and Haavelmo) or 'structural relationships' (e.g. Lucas and Sagent) are used. Alternatively, one may talk about 'policy invariant parameters' or 'super exogenous variables'. Simon, on the other hand, used the term 'causal relations'. Haavelmo (1944, p. 3), Simon (1952, p. 53 in *Models of Man*), and more recently Hendry (Hendry et al. 1990, p. 184) explicitly deny causal relationship independent of our own causal representations. Therefore, they prefer other terms than the term 'causal'.

The paper discusses what we shall understand with the term 'causal relationships'. Furthermore, it criticizes the procedure of testing the Lucas critique. Finally, it suggests a new approach for identifying (and testing) causal relationships.

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Reduced rank techniques for testing casual relationships

Let x_t be an n-dimensional vector of non-stationary $I(1)$ variables, η a vector of intercepts, α and β are matrixes of dimension n x r (where r is the number of cointegration vectors) and $\beta' x_t$ is $I(0)$. Furthermore, Δ is the difference operator; Λ is an n x q matrix of coefficients and d_t is an q-dimensional vector of shift dummies. The residual ε_t is assumed to be white noise Gaussian ($\varepsilon_t \sim N(0,\Omega)$).[19]

(A-1) $$\Delta x_t = \eta + \Lambda d_t + \alpha\beta' x_{t-1} + \varepsilon_t$$

The matrix Λ can have reduced rank, s. Therefore, we write $\Lambda = \psi\varphi'$, where ψ and φ have dimension n x s and q x s respectively, with $s \le \min(n, q)$.[20] Furthermore, let $\psi = (\psi_1', \psi_2')'$, where ψ_1 has dimension $(n\text{-}s)$ x s, and ψ_2 has dimension s x s. Assume that ψ_2 has full rank. Then we can construct the orthogonal compliment of ψ as $\psi_\perp' = \left(I_s, -(\psi_2)^{-1} \cdot \psi_2\right)$. Since $\psi_\perp'\Lambda = \psi_\perp'\psi\varphi' = 0$, pre-multiplying (A-1) with $\psi_\perp'$ yields

(A-2) $$\psi_\perp'\Delta x_t = \psi_\perp'\eta + \psi_\perp'\alpha\beta' x_{t-1} + \psi_\perp'\varepsilon_t .$$

Now we have the basis for identifying causal relationships. Partitionate $x_t = (y_t', z_t')'$ where y_t is a vector of dimension n-s with target variables, and z_t is a vector of dimension s with policy instruments. Similarly, partitionate $\eta = (\eta_y', \eta_z')'$ and $\alpha = (\alpha_y', \alpha_z')'$ with dimensions as above. The method described above can then be used to express the target variables as a function of the policy variables.

(A-3) $$\Delta y_t - \lambda\Delta z_t = (\eta_y - \lambda\eta_z) + (\alpha_y - \lambda\alpha_z)\beta' x_{t-1} + u_t ,$$

where $\lambda = (\psi_2)^{-1} \cdot \psi_2$ and $u_t = \varepsilon_{y,t} - \lambda\varepsilon_{z,t}$. The marginal model of the policy variables is

(A-4) $$\Delta z = \eta_z + \psi_z\varphi d_t + \alpha_z\beta' x_{t-1} + \varepsilon_t .$$

[19] For simplicity we do not include more than one lag.

[20] If $q<n$ it is always possible to identify linear relationships between the variables. However, these may be spurious relationships that would have been rejected if there had been more policy changes in the system. (See also the bullet items on the next page.)

Let $\omega = \sigma_{yz}\left(\sigma_z^2\right)^{-1}$, where σ_{yz} is the covariance between $\varepsilon_{y,t}$ and $\varepsilon_{z,t}$, and σ_z^2 is the variance of $\varepsilon_{z,t}$. If $\omega=\lambda$, then expected and unexpected changes in z affects y in the same way. Then the parameters in (A-3) are super-exogenous, cf. Engle et al. (1983). If in addition $\alpha_z=0$ (i.e. the policy variables are weakly exogenous with respect to the cointegrating relationship), the parameters in (A-3) could have been estimated efficiently form (A-3) alone.[21]

However, there may be some problems:

- What if s (i.e. the rank of Λ) does not correspond to the number of policy instruments? If s is less than the number of policy instruments there has been less than s (independent) structural changes in the economy. Then it is impossible to distinguish the effect from the different policy instruments to the target variables since the changes in the policy instruments are not linearly independent. If, on the other hand, s exceeds the number of policy instruments, there is impossible to identify conditional relationships for all the target variables without structural breaks. That implies that there are not as many stable causal relationships as there are target variables.

- What if the matrix ψ_2 does not have full rank? Then (if s corresponds to the number of policy instruments), both the problems above apply at the same time: First, there are not as many independent structural changes in the policy instruments as there are policy instruments, and therefore it is impossible to distinguish the effect from the policy instruments to the target variables. Second, (if s corresponds to the number of policy instruments) it will be impossible to identify conditional relationships for all the target variables without structural breaks, because the breaks in the marginal process for (at least some of) the target variables are independent of the breaks in the policy instruments.

The most common problem of the ones mentioned above is probably when s is less than the number of policy variables. Then there are not enough (independent) changes in the policy variables in order to identify the causal relationships. Then it is not enough information in the data and we have to apply other sources to identify the causal relationships. Frisch (1938) suggests using interviews as a substitute. To our knowledge no one has applied interviews in empirical works in order to compensate for lack of information in the data.

[21] Alternatively, we could define $\upsilon = \varsigma_{yz}\left(\sigma_z^2\right)^{-1}$, where ζ_{yz} is the correlation between u_t and $\varepsilon_{z,t}$. Then testing $\omega=\lambda$ corresponds to testing $\upsilon=0$.

An alternative to the interview method when there are not enough changes in the policy to determine their causal effect on target variables is to assume that expected and unexpected policy changes has the same effect. This implies to estimate a conditional system with respect to these policy instruments.

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