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Policy implications of the Lucas Critique empirically tested along the global financial crisis

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Abstract

This study is the first attempt to facilitate the substantial change in post-crisis monetary policy of the Fed to test the validity of Lucas Critique toward exploring implications of such changes for policymaking. Global financial crisis, asking for fundamental regime alterations presented an invaluable opportunity to test the empirical validity of Lucas Critique. We make use of quarterly US data over 1990–2015 to test for superexogeneity, the rejection of which lends support to Lucas Critique. We define the marginal models for wealth, GDP and Treasury Bill rate to construct the conditional model of money demand following Hendry (1988). Our results reject superexogeneity of the policies and report the support for Lucas Critique. We discuss about the details and consequences of the monetary policy followed to suggest arguments to prolonging debates on policy discussions.

JEL classification: C22; C52; E41; E42; E52; E58

Keywords: Lucas Critique; Monetary policy; Superexogeneity; Invariance; Rational expectations

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1. Introduction and research background

1.1. Lucas Critique

Lucas Critique (LC), with its empirical validity still under debate more than four decades after its inception, has serious policy implications. Economic agents, firms and institutions in any country under the administration of financial and fiscal authorities are directly influenced from policy objectives and regime changes. The impact of policy changes on nominal and real macroeconomic indicators is critical and crucial. Yet, there is still harsh debate on the consequences of monetary and fiscal regime changes. In this regard, critique posed by 1995 Nobel Laureate Robert E. Lucas is a milestone to assess the results of policy changes and presents beneficial and effective clues about policy design.

Lucas argues that macroeconometric models that do not handle optimizing behavior of rational agents at policy changes are subject to failure. Assuming that the agents are forward looking, their economic decisions will depend partly on future actions of the policymakers. Lucas suggests that the linkage between the regime changes by policymakers in the future and forecasts of agents handling these changes should be included in econometric models. Lucas's contribution to policy evaluation was revolutionary since he has demonstrated that conventional backward-looking models ignored the formation of expectations which is the key determinant of agent's behavior in case of a policy regime change. LC depends on the formation of expectations substantially. By his critique, Lucas made it clear that policies cannot be evaluated within the classical theory, and conventional macroeconometric models cannot be used to investigate policy changes since the structural parameters do change as policy does.

The critique can be summarized by the most quoted expression of it as "Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models." Implicitly stated in this expression is that the agents' optimization problems comprise of parameters used in policy rules. To be more specific, following the notation in Ericsson and Irons (1995), assume that the economy is characterized by the decision rule optimized by the agents, F(.), and the policy reaction function, G(.):

$$y_{t+1} = F(y_t, x_t, \theta, \varepsilon_t)$$

$$x_t = G(y_t, x_{t-1}, \lambda, \eta_t)$$

where y_t is the endogenous variable, x_t is the exogenous variable, ε_t and η_t are shocks at time t, and θ and λ are the parameters of the corresponding functions. The agent optimizes F and has to take care of parameters in G since θ may depend on λ and thus when λ changes due to a regime shift, θ changes directly. The critique posed by Lucas is on theoretical ground and is in deep need of empirical support.

Lucas in his original 1976 paper exemplifies this process with Friedman's consumption function, taxation, investment demand, and Phillips curve. Lucas had criticized the facilitation of models to estimate the impact of alternative policies arguing that the parameters included in the models are not invariant to shifts in policy. In case of a change in policy, the rational agents modify their expectations and new decision rules are fixed. That is why models based on the decision rules vary due to policy shifts and models without this feature are inferior. The response of macroe-

conomists to Lucas Critique was the introduction of Dynamic Stochastic General Equilibrium (DSGE) Models where parameters corresponding to preferences and technology are preserved unchanged even if there is a shift of the policy regime with the inevitable assumption of correct DSGE model specification. In a typical DSGE model, variables representing technology and preferences do not vary and are not subject to changes in policy regimes. Once the structural model is correctly specified, estimation of parameters belonging to these variables will not be biased. This very feature of the DSGE models make them free from LC.

1.2. Rational expectations

The expectations of the agents are at the heart of the critique. LC focuses on how parameters of the econometric models enter the optimization functions of the economic agents. That is, the parameters that policymakers set by changing the policy regimes have to enter the optimization problems of the agents. As policy regimes change, the nature and thus the preferences of the agents do not change but their expectations do. The expectations are addressed to be forward instead of backward-looking after the popularization of the rational expectations revolution in macroeconomics which build on the earlier paper of Muth (1961) that made use of the adaptive expectations by Friedman (1956) and Cagan (1956). The implications of rational expectations on policy analysis are essential, fundamental and remarkable. The main findings of the impact of rational expectations hypothesis on policy regime changes are by Barro (1976), Kydland and Prescott (1977), Lucas (1976), Sargent, Fand, and Goldfeld (1973), Sargent and Wallace (1975).

The rational expectations hypothesis assume that the individuals know the structure of the economy and past values of all variables therein. In addition, the agents are assumed not to make systematic errors since the information set available includes past errors. Shiller (1978), Fischer (1980), Begg (1982), and Sheffrin (1996) are the initial references to rational expectations while earlier studies of rational expectations hypothesis on monetary policy include Sargent (1977), Sargent et al. (1973), Lucas and Sargent (1981), and Lucas and Prescott (1971). The main theme of the debate was policy ineffectiveness that necessitates no effect of anticipated systematic monetary policy on mean and variance of output. That is, systematic monetary policy changes cannot have real effects on the economy. The early versions by Friedman (1968) stated that output was independent of monetary policy in the long run. The paper by Sargent and Wallace (1975) concluded the same for short run. The assumption of agent's optimization based on rational expectations is so strong to eliminate systematic forecast errors associated with adaptive, regressive, extrapolative or other types of expectations.

Although rational expectations hypothesis deserves its reputation since it addresses the solution to a set of debates, it has introduced its own problems and shortcomings. The main criticism is the so-called construction of the true structure of the economy by individuals who do not know enough about the economy and modeling mathematics while wise economists debate on main and simple issues. Besides, "How do the agents rationalize expectations and learn from the mistakes to get rid of systematic forecast errors?" is another key question to be answered satisfactorily.

A remarkable fundamental problem with the LC is time-inconsistency stressed by the seminal work of Kydland and Prescott (1977). The optimal policies with forward-looking expectations may become sub-optimal through time, known as time-inconsistency or dynamic inconsistency. That is, ex ante optimal policies may become sub-optimal ex post. LC itself was criticized by many others, as Hendry (2002) indicated "...the critique has been criticized in turn by many authors, including Gordon (1976), Sims (1986), Sims, Goldfeld, and Sachs (1982) and Hendry (1988), and most recently by Salmon and Marcellino (2001), who show the internally-inconsistent use of

'rationality' in Lucas's analysis. There is also scant evidence of its operation empirically (see, in particular, Ericsson & Irons 1995)". In addition, there have been many other such criticisms after early 2000s. See Smith (2009) for a list of arguments against LC. Although the LC is generally accepted and integrated to mainstream macroeconomic theory, it did not pass rigorous empirical test to assert its validity.

On the other hand, Mishkin (1995) indicates that the LC was revolutionary and underlines the role of expectations as: "Policymakers now recognize the importance of expectations to the outcome of particular policies because of the rational expectations revolution: before the advent of rational expectations, expectations were typically ignored by policymakers when conducting policy analysis" But, there is lack of guidance to policymakers as indicated by Sims (2007) as ". . .I also criticized the academic econometric and macroeconomic literature, which took no interest in policy modeling and had little guidance to offer policy modelers."

1.3. Global financial crisis and regime change in monetary policy

There are several challenges against testing the LC empirically one of which is addressing a fundamental change in policy regime that is fortunately provided to us by the Global Financial Crisis (GFC), although we are extremely upset to experience the consequences of it. The 2008 financial crisis had enormous effects on the global economy and posed objections to traditional policy making. The so-called credit tsunami (by Alan Greenspan) of the century, incepted by the mortgage markets, started hitting the financial markets and thus, institutions in June 2007. As a result of the initial devastating strikes of the huge waves, one of the largest US firms that had been a main pillar of the financial system since 1850, Lehman Brothers, filed for bankruptcy, as well as the American International Group (AIG), a giant insurance conglomerate. These two in addition to many similar others, triggered the fears that many institutions would be suffering from substantial losses due to unpaid borrowings that would threaten their solvency. The panic spread to real markets very shortly. These were reflected to the statistics; in the US, the 18-month recession between 2007 and 2009 was the longest recorded post WWII. It led to 6.3% decline in employment and 5.1% fall in output. Stock prices fell by 50% from October 2007 to March 2009 ("Recession in Perspective"/Federal Reserve Bank of Minneapolis). Tsunami reaching the other parts of the globe through financial and trade channels soon, decreased the Baltic Dry Index, underlining shipping volume and thus international trade, by 50% in October 2008. Japan and Korea, for instance, had 31% and 26% declines in their industrial output from January 2008 to January 2009 (Alzaabi, 2013). The global financial crisis in its "Great Recession" stage marked the worst economic contraction since WWII (Verick & Islam, 2010). Mishkin (2009) indicated that this was the worst financial crisis that the United States has experienced since the Great Depression. Facing the worst financial crisis ever since the Great Depression the Federal Reserve had aggressively lowered the federal funds rate target from 5.25% in September 2007 to 0 to 0.25% in December 2008 (Mishkin, 2009). As an attempt to alleviate the destructive consequences of the crisis, when Obama's term at the White House started in 2009, he signed the fiscal stimulus package to increase federal government spending by about $499 billion and reduce taxes by around $288 billion. But managing the detrimental influence of the crisis was extremely complex and beyond such voluminous fiscal policy tools.

The former president of the ECB, Jean-Claude Trichet indicated that the defining characteristic of the global financial crisis had been so perplexing to ask for non-standard monetary policy measures. Although the financial markets of the globe were somehow ubiquitous, the approaches by the central banks were different designed for peculiar economies and their structures ranging

from enhanced credit support and credit easing to quantitative easing and interventions in foreign exchange and securities markets. Besides, Fahr, Motto, Rostagno, Smets, and Tristani (2011) state "The initial turmoil and the subsequent crisis that swept through financial markets over the past three years have posed unprecedented challenges for central banks. Their policy responses have been equally unprecedented and have involved non-standard measures, i.e. actions that go beyond the usual changes in a "policy" interest rate." They reason the use of unprecedented non-standard monetary policy as the central banks responsibility to prevent liquidity problems turning into solvency problems with an eventual breakdown of the monetary transmission mechanism. In addition, malfunctioning interbank and other financial markets called upon central banks to take on a more active financial intermediation role.

There was urgent need for accommodative policies of the monetary authorities. As Mishkin (2011b) mentioned, the contractionary shock from the financial crisis was so severe that it overwhelmed the ability of conventional monetary policy to counteract it. One of the remarkable changes in validating unconventional monetary policy has been the Quantitative Easing (QE) program administered by the US after the crisis, and followed by several other central banks. There is a mounting body of recent research on QE and its effects (El-Shagi & Giesen, 2013; Karagiannis, Panagopoulos, & Vlamis, 2010; Mishkin, 2011b; Rogoff, 2017; Taylor, 2014) and almost all of them agree on the fact that QE was, although risky and not desirable, best possible option to respond to the ongoing and future contractionary shocks to the economy. In the process of implementing QE policies, the FED's balance sheet dramatically expanded from around $700 billion in 2008 to $2.1 trillion in June 2010, with most of the increases absorbed by the banking system as excess reserves (Bernanke, 2012). And according to CNBC, the Fed's total assets in its balance sheet ballooned from $900 billion to $4.5 trillion between 2008 and 2015 (https://www.cnbc.com/2017/11/24/the-fed-launched-qe-nine-years-ago–these-four-charts-show-its-impact.html as of 8 Nov 2018).

QE being applied practically at the same time commenced re-consideration of traditional monetary policy-making which may lead to shed light on the perplexing debate of the LC. Lucas (1976) argues that policy shifts and/or structural changes of the expectation-generating mechanism lead to unstable econometric models, since such changes will alter actual structural parameters and the estimated coefficients in the model. The QE as an agreed upon policy alteration results in the expectation modification of economic agents as well as institutions. In order to be an effective policy tool, parameters of the econometric model must be invariant to these changes. The role of the LC has become very important in evaluating and analyzing the implications of the policies undertaken after the crisis because it may have a powerful influence in decreasing the application of the standard monetary models for the policy analysis. Applicability of the LC, also known as the validity of "deep structural parameters" (Fair, 1987) is significant to accurately assess the future effects of the consequent policy shifts on economic activity and agents' expectations that are assumed to be "rational".

1.4. Main motivation

The empirical testing of the LC is never found satisfactory. As Malinvaud (1997) underlined "Indeed the small illustrative models presented by Lucas and others, showed no more than a possibility and were in no way tested as to their empirical validity." He continued his criticism stating that ". . .neither Lucas nor the New Classical macroeconomists had tried to test the empirical validity of the Critique: At the time, many macroeconomists, especially [me], were not convinced

of the scope of [the Lucas Critique], although they recognized the correctness of the remark that inspired it."

Lucas and Sargent (1981), in their famous "After Keynesian Macroeconomics", indicate "Yet the question of whether a particular model is structural is an empirical, not a theoretical one." Later on, when introducing his collected works in Studies in Business Cycle Theory, Lucas and Sargent (1981) argues again: ". . .this presumption [about policy-invariance] seems a sound one to me, but it must be defended on empirical, not logical grounds, and the nature of such a defense presumably would vary with the particular application one has in mind."

Despite a large amount of research on the LC, there is a surprising lack of empirical study on the issue of testing the empirical validity of critique in the literature.[1] The reasons are various, such as the scarcity of observational period attributed to fundamental change in policy, small samples, and essentially, on top of which is the absence of generally accepted methodology. Unfortunately, neither Lucas nor his immediate companions as well as his followers did not introduce the methodology to test the empirical relevance of the theory. In later years, Engle and Hendry (1993) introduced the concept of superexogeneity, which has appeared to be an effective tool to test the empirical relevance of the Lucas Critique. Subsequent papers (Ericsson & Irons, 1995; Lindé, 2001) have demonstrated how this concept can be applied to check for policy invariance in econometric models. In this way, superexogeneity has been largely performed to test the effects of regime shifts in monetary, exchange rate, consumption and savings rate behavior (Karunaratne, 1996). The works by Boug (1999), Favero and Hendry (1992), Ericsson and Irons (1995), and Lubik and Surico (2010) highlight the importance of the use of the superexogeneity test and consider it as the main empirical tool to assess LC validity after the policy shifts.

There are favorable reasons behind using superexogeneity to test for the validity of LC. As Engle and Hendry (1993) underline, some problematic issues arise when the traditional tests in the literature are used in order to find the relevance of the parameter stability with lack of guidance on exact dates and numbers of breaks. The entire test is misguiding when incorrect days are selected for testing the existence of the structural break (Engle & Hendry, 1993). In such cases, testing for exogeneity with its three different versions is preferable. In the literature three versions of exogeneity are defined: Weak exogeneity is employed for estimation purposes, strong exogeneity is required for forecasting, and superexogeneity (Superexogeneity) is facilitated for policy analysis. Although the superexogeneity test has been used to check for the effects of regime shifts in monetary, exchange rate, consumption and trade policies, there is no attempt on its application with QE in the literature

In the context of these important policy questions, the present period offers an invaluable opportunity to test the validity of LC empirically toward suggestions on policy design. This study applies superexogeneity test (Engle & Hendry, 1993) to detect the relevance of the LC in modeling the demand for money in the U.S. after the three QE attempts. The related literature recommends that the LC should be assessed in the context of economic models that would deal explicitly with expectations, such as the money demand function used in this paper (Engle & Hendry, 1993; Hurn & Muscatelli, 1992). We also provide policy discussions that shed light on the fragility of conventional models to capture existing information and provide correct policy implications in the environment of major shifts such as QE. As per the conclusion of the empirical testing of superexogeneity, rejection over the sample period indicates that the parameters are variant/sensitive to the policy changes and implies that the LC is relevant.

[1] According to Ericsson and Irons (1995) there were 513 SSCI citations between 1976–1990.

Empirical studies making use of superexogeneity in the literature are scarce and studies based on superexogeneity methodology to test the LC in monetary models, and almost all existing papers are outdated. One of the rare studies is by Hurn and Muscatelli (1992) who found that the LC may not be relevant in the case of the demand for money (M4) in the UK. Others such as Karunaratne (1996), Valadkhani (1998), Caporale (1996), Faria and León-Ledesma (2005), Belke (2000), Oliveira and Santos (2007), Psaradakis and Sola (1996), Santos (2004), and Liu and Morley (2014) investigated the same issue but with applications to trade, consumption, business cycle and financial models using data chronologically back to older decades. Following the findings in superexogeneity methodology from earlier studies, this paper is organized as follows: Section 2 briefly describes the procedures for testing invariance and superexogeneity hypotheses. Section 3 outlines and estimates a model of the demand for money in the U.S. The following Section 4 provides discussions of the estimated results with policy implications and finally Section 5 concludes.

2. Superexogeneity testing

There have been numerous attempts to test the constancy of parameters over the historical period. One of the initial specification tests is by Chow (1960), which simply questions for interactions with dummy variables (Engle & Hendry, 1993). In contrast, superexogeneity is specifically designed to ascertain whether parameters are likely to remain constant in response to changes in policy regime over the historical period. As an important measure of parameter stability, it is closely related to the test of invariance, but the causes, periods and magnitudes of changes are identified by the economic circumstances, and the historical evidence for regime changes are embodied in the conditioning variables. The superexogeneity test is perfectly applicable to the models of money demand, and the Phillips curve, in particular. Indeed, the instability of the Phillips curve, especially at times of external shocks and regime changes, was probably the most famous application of the influential "Lucas Critique" (Bajo-Rubio, Díaz-Roldán, & Esteve, 2007). Due to the lack of opportunities of major monetary policy shifts until the global crisis, the superexogeneity tests were used in applications with exchange rate, consumption, and savings models that entail relatively minor policy shifts in the literature. The studies include Ericsson (1992), Favero and Hendry (1992), Caporale (1996), Karunaratne (1996), Valadkhani (1998), and Habibullah, Azali, and Baharumshah (2001) who examine the relevance of the Lucas Critique.

Many econometric studies require the distinction between exogenous and endogenous variables to build the model for statistical inference. In this regards, exogeneity is the key to many econometric analyses, but there are difficulties concerning the very definition of the term (Engle, Hendry, & Richard, 1983). This inconvenience asks for further investigation of estimation on model parameters. Fortunately, Engle et al. (1983) contribute to the literature arguing that the superexogeneity is closely related to the Lucas Critique and, as mentioned in Caporale (1996), serves as an important instrument for policy analysis.

We provide the brief explanation of the superexogeneity testing procedure employed to assess the relevance of the LC below. A more detailed and complete procedure of the testing strategy for superexogeneity is provided by Engle et al. (1983). We start by defining the joint, conditional and marginal distributions following Engle et al. (1983) as:

$$F_k(k_t;\theta_t) = F_{y|x}(y_t|x_t;\lambda_{1t}).F_x(x_t;\lambda_{2t})$$

where $F_{y|x}$ and F_x are conditional and marginal models.

As per two of the three versions of exogeneity mentioned; a variable x_t is said to be *weakly exogenous* for a set of parameters of interest Ψ (some functions of θ) in a conditional model of a variable Y_y with parameters λ_1 with $k_t = (y_t, x_t)'$ if:

i) is a function of the parameters λ_{1t} alone;
ii) λ_{1t} and the parameters of the marginal model for x_t, and λ_{2t} are variation free, which implies that there is no loss of information about Ψ from neglecting the marginal model (Caporale, 1996).

x_t is defined as *super exogenous* for Ψ if:

i) x_t is weakly exogenous for Ψ,
ii) changes in λ_{2t} do not cause changes in λ_{1t}. Here, a parameter is considered invariant for a class of interventions if it remains constant under these interventions. A model is invariant for such interventions if all its parameters are (Engle et al., 1983)

Illustratively, Engle et al. (1983) model the linear regression equation, which is hypothesized to represent the constant conditional mean of a random variable y_t given another random variable x_t as well as other information. These technical definitions are key to suggesting principles for designing policies since distinction between exogenous and endogenous variables enables us to figure out variables invariant to policy changes. Consider the joint distribution of these variables conditional normal with the following conditional means:

$$\begin{aligned} E[y_t|I_t] &= \mu_t^y \\ E[x_t|I_t] &= \mu_t^x \end{aligned} \tag{1}$$

and covariance matrix

$$\sum\nolimits_t = \begin{bmatrix} \sigma^{yy} & \sigma^{yx} \\ \sigma^{xy} & \sigma^{xx} \end{bmatrix} \tag{2}$$

where x_t and y_t are conditional on the information set I_t that contains their past values, and current and past values of other valid conditioning variables z_t. The conditional expectation of y_t on x_t can be expressed as:

$$E(y_t|x_t) = \lambda_t(x_t - \mu_t^x) + \mu_t^y \tag{3}$$

and

$$y_t - E(y_t|x_t) = \omega_t \tag{4}$$

where λ_t is the regression coefficient of y_t on x_t equals to σ^{yx}/σ^{xx}, and ω_t is the conditional variance equals to $\sigma^{yy} - (\sigma^{yx})^2/\sigma_t^{xx}$.

The conditional mean of y_t and x_t is considered in the following behavioral relationship as:

$$\mu_t^y = \beta\mu_t^x + z'_t\gamma \tag{5}$$

Combining Eqs. (3)–(5) yields:

$$y_t = \beta x_t + z'_t\gamma + (\lambda_t - \beta)(x_t - \mu_t^x) + \omega_t \tag{6}$$

To sustain this regression analysis with weakly exogenous, constant and invariant parameters we need the following three conditions:

- *Weak exogeneity* of x_t for the parameters of interest. This requires that μ_t^x, σ_t^{xx}, and σ_t^{yx} do not enter the conditional model, which is satisfied if $\lambda_t = \beta$.
- *Constancy* of the parameters that requires $\lambda_t = \lambda$. Since $\lambda_t = \sigma^{yx}/\sigma^{xx}$, the regression model is homoscedastic if $\sigma^{yy} = \omega + \lambda\sigma_t^{xx}$.
- *Invariance* of β to the changes in the processes generating z_t.

With these conditions satisfied, a standard regression model to be estimated is:

$$y_t = \beta x_t + z'_t\gamma + \omega_t \tag{7}$$

Toward testing for the empirical validity of the LC, Engle and Hendry (1993) show that the effects of policy shifts can be formulated as the impact of changes in the moments of x_t on the parameters of β in the following linear expansion form:

$$\beta = \beta_0 + \beta_1\mu_t^x + \beta_2\sigma_t^{xx} + \beta_3(\sigma_t^{xx}/\mu_t^x) \tag{8}$$

By substituting (8) into (7) we obtain:

$$\mu_t^y = [\beta_0 + \beta_1\mu_t^x + \beta_2\sigma_t^{xx} + \beta_3(\sigma_t^{xx}/\mu_t^x)]\mu_t^x + z'_t\gamma \tag{9}$$

or in the following form as a regression:

$$y_t = \beta_0 x_t + z'_t\gamma + (\lambda_t - \beta_0)(x_t - \mu_t^x) + \beta_1(\mu_t^x)^2 + \beta_2\mu_t^x\sigma_t^{xx} + \beta_3\sigma_t^{xx} + \varepsilon_{1t} \tag{10}$$

For superexogeneity, the moments of x_t should be insignificant and λ_t must be constant over time. However, when Σ_t is not constant, Engle and Hendry (1993) suggest a linear expansion, such as:

$$\lambda_t = \sigma^{yx}/\sigma^{xx} = \lambda_0 + \lambda_1\sigma^{xx} \tag{11}$$

By combining Eqs. (6), (8) and (11) we obtain a general alternative regression for the case of non-constant Σ_t:

$$\begin{aligned} y_t = {} & \beta_0 x_t + z'_t\gamma + (\lambda_0 - \beta_0)(x_t - \mu_t^x) + \lambda_1(x_t - \mu_t^x)\sigma^{xx} + \beta_1(\mu_t^x)^2 \\ & + \beta_2\mu_t^x\sigma_t^{xx} + \beta_3\sigma_t^{xx} + \varepsilon_{2t} \end{aligned} \tag{12}$$

Eqs. (10) and (12) can be implemented to test for superexogeneity by examining both a conditional model and marginal models for the conditioning variables. Here, we can interpret conditional and marginal models as agents' and policy makers' decision rules, respectively (Giersbergen & Kiviet, 1996). Since policy makers often set targets for the endogenous variables that determine the behavior of the economic agents, policy rules are affected from past economic outcomes (Banerjee, Hendry, & Mizon, 1996). Economically, superexogeneity occurs when the agents form their expectations without using models, for instance the high cost of information or a low level of benefits from model-based expectations (Ericsson, Hendry, & Mizon, 1998).

3. Models and test results

We start by reporting the estimates of the policy reaction function using (10) and (12). The conditional and marginal models are constructed with the demand for money in the US to check if the LC is relevant after the post-crisis monetary policy shift. Data are quarterly and capture the period between 1990 and 2015. The conditional model defines the real money demand as a dependent variable (*MD*). We assume that money demand is identified by a cointegrating vector of both scale variables and the variables representing the opportunity cost of holding money. Judd and Scadding (1982) and Hurn and Muscatelli (1992) model similar relations for their studies with different specifications and analysis.

The scale variables in the money demand function represent wealth effects and transactions. Real wealth, which captures the asset motives of holding money, is represented by the proxy of real financial assets of non-financial corporate sector as a share of GDP (*W*/*GDP*). The other scale variable is real GDP (*GDP*), representing economic activity and hence, transactions based on demand for money.

The second set of variables denotes the opportunity cost of holding money, which consists of both its own rate and alternative returns on money. We did not include own rate of money, since the current deposits' rates have long been very low in the US and do not capture observable changes. As the measure of alternative returns, we added the interest rate on the 3-month US Treasury Bill (*TB*), regarded as a close money-substitute foregone by holding money. All variables were converted to real values using the GDP deflator and come in log forms. The corresponding marginal models were constructed for real wealth, GDP and interest rates as shown in Table 1.

There are two conditions for superexogeneity as mentioned: for weak exogeneity, the resulting residuals from the marginal model must be insignificant in the conditional model. As per superexogeneity (or structural invariance of the parameters), the parameters of the conditional model must be insensitive to induced structural changes in the marginal model parameters. Policy analysis generally involves changing the marginal process of x_t. For a valid analysis under such changes, the parameters λ_1 should be invariant to those changes/interventions. Ericsson (1992), Hurn and Muscatelli (1992), Engle and Hendry (1993), Hendry (1995) and Valadkhani (1998) state the use of a dummy variable to test superexogeneity empirically. This variable is inserted into both conditional and marginal models to represent structural change or policy shifts. Structural invariance is satisfied, if it comes out significant in the marginal model and simultaneously insignificant in the conditional model. But, the null of superexogeneity will be rejected if the dummy added to the basic conditional model is proven to be significant statistically. The regime shift or structural change dummy variable in this study is defined as DUM_t, which captures the QE policy and takes the value of zero until the fourth quarter of 2008, and one thereafter.

In the first step of estimation, we conducted ADF tests to check for stationarity of the variables and detect their orders of integration. The test results revealed that all variables are integrated of order one, I(1).

We report the estimation results of the parsimonious dynamic conditional model for money demand based on (13) and derived by the general-to-specific (GTS) approach (Davidson, Hendry, Srba, & Yeo, 1978; Engle et al., 1983). The short-run dynamics in the model are captured by the cointegrating vector as an error correction mechanism (ECM_{t-1}), which is statistically significant. The included dummy variable is of particular interest to us, since it captures structural changes. As expected, the sign of its coefficient estimate is positive, since the QE policy would induce higher demand for money. Its coefficient is also significant in the conditional model, validating

Table 1
Marginal models for x_t.

Marginal model for wealth

$$\Delta W_t = \underset{[0.009]}{-0.034} ECM_{t-1} + \underset{[0.077]}{0.417}\Delta W_{t-2} + \underset{[0.015]}{0.089}\Delta SMI_t + \underset{[0.001]}{0.002} DUM_t$$

Sample period: 1990Q1–2015Q4
$R^2 = 0.417 \quad \bar{R}^2 = 0.400$
$\sigma = 0.005 \quad DW = 1.62$
Serial correlation F (2,98) = 2.805
Heteroscedasticity ARCH F (2,99) = 0.551
Chow breakpoint test F (3,98) = 2.901

Marginal model for GDP[a]

$$\Delta GDP_t = \underset{[0.019]}{-0.03} ECM_{t-1} + \underset{[0.083]}{0.463}\Delta GDP_{t-1} + \underset{[0.074]}{0.161}\Delta L_{t-1} + \underset{[0.038]}{0.118}\Delta CAP_t + \underset{[0.0005]}{0.001} DUM_t$$

Sample period: 1990Q1–2015Q4
$R^2 = 0.286 \quad \bar{R}^2 = 0.258$
$\sigma = 0.002 \quad DW = 2.263$
Serial correlation F (2,97) = 3.44
Heteroscedasticity ARCH F (2,99) = 3.106
Chow breakpoint test F (4,96) = 7.736

Marginal model for treasury security

$$\Delta TB_t = \underset{[0.019]}{-0.063} ECM_{t-1} + \underset{[0.072]}{0.629}\Delta TB_{t-1} - \underset{[0.09]}{0.135} + \underset{[31.895]}{31.62}\Delta INF_t + \underset{[0.078]}{0.135} DUM_t$$

Sample period: 1990Q1–2015Q4
$R^2 = 0.474 \quad \bar{R}^2 = 0.454$
$\sigma = 0.307 \quad DW = 2.134$
Serial correlation F (2,96) = 2.37
Heteroscedasticity ARCH F (1,100) = 1.996
Chow breakpoint test F (4,96) = 3.092

[a] HAC estimation results.

doubts on the condition of the structural invariance. This means that shifts in the monetary regime have significant considerable effect on money demand, highlighting the importance of behavioral factors such as expectations, as stated by the LC.

The serial correlation and heteroscedasticity test results are satisfactory. Furthermore, we report the results of cumulative sum (CUSUM) test (Fig. 1) documenting that the regression is stable over the sample period.

Conditional model for US money demand

$$\begin{aligned}\Delta MD_t &= \underset{[0.002]}{-0.003} ECM_{t-1} + \underset{[0.076]}{0.507}\Delta MD_{t-1} + \underset{[0.074]}{0.24}\Delta MD_{t-3} \\ &\quad + \underset{[0.022]}{0.044}\Delta(W/GDP)_{t-4} - \underset{[0.101]}{0.24}\Delta GDP_{t-1} \\ &= + \underset{[0.088]}{0.358}\Delta GDP_{t-3} + \underset{[0.0005]}{0.001}\Delta TB_{t-2} - \underset{[0.0005]}{0.002}\Delta TB_t \\ &\quad - \underset{[0.093]}{0.045}\Delta GDP_t + \underset{[0.0005]}{0.001} DUM_t\end{aligned} \tag{13}$$

Sample period: 1990Q1–2015Q4
$R^2 = 0.594 \quad \bar{R}^2 = 0.555$
$\sigma = 0.0023 \quad DW = 2.67$
Serial correlation F (4,90) = 1.548
Heteroscedasticity ARCH F (4,95) = 0.9934

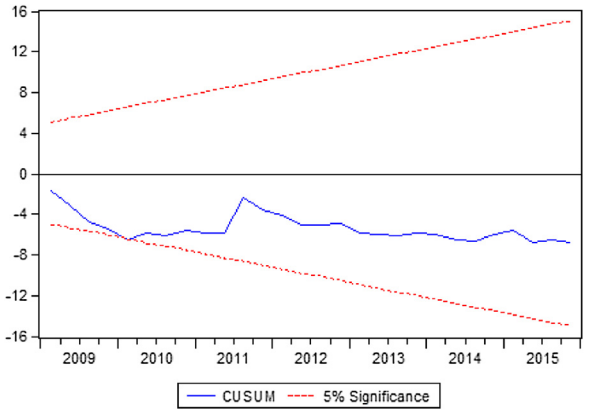

Fig. 1. CUSUM of the conditional model.

The next step in the procedure is to estimate the marginal models for x_t, reported in Table 1. We built and estimated separate marginal models of the mentioned scale variables – wealth, GDP and Treasury Bill rates. In building the models, we relied on basic macroeconomic determinants (Hurn & Muscatelli, 1992). As a main determinant of wealth, we put S&P Stock Market Index (SMI_t) and its own lag. Second marginal model explains the GDP as functions of labor (L, measured by labor participation ratio) and real capital (CAP) based on Cobb-Douglas production function (all variables are in log forms). Lastly, the third marginal model testifies interest rate (Treasury Bill rates) by inflation (INF, measured by the GDP deflator) and its lagged value from the previous period. Marginal models qualify to be stable and reveal mainly satisfactory diagnostic results. The marginal model of GDP was estimated using HAC errors to account for heteroscedasticity detected while testing. The signs of all significant coefficient estimates are consistent with established underlying theory, and the ECM displays significant coefficients in all models. Most importantly, included dummies, which capture a major QE shift, also have significant coefficients in all models. This indicates that implementation of the QE plays a crucial role in modeling main economic relationships in policy modeling, by validating changes in the actual structural parameters of the econometric models. Our empirical findings ascertain that the parameters in the econometric model of the money demand relationship, which is largely used by policymakers, have changed in response to changes in QE regime after 2008. Therefore, the consequent actions of the economic agents, such as their decisions concerning asset accumulation, economic activity and purchase of bonds would largely depend on their expectations, based mainly on the QE policy itself.

Table 2 displays important test results to provide further support to the validity of the LC associated with policy-based expectations. Entire set of residuals from the marginal models are statistically insignificant in the conditional model to document that the condition of weak exogeneity is satisfied. On the other hand, the same is not true for the condition of structural invariance, since the dummy is simultaneously significant in both the marginal model(s) and the conditional model. Based on these findings we conclude that the null of superexogeneity is rejected. We comment that the model we constructed for money demand is prone to the LC.

Table 2
Superexogeneity test results.

Test	Null hypothesis	*t*-statistic
Weak exogeneity	$\varepsilon_t^W = 0$	1.558
	$\varepsilon_t^{TS} = 0$	0.061
	$\varepsilon_t^{GDP} = 0$	−1.635
Invariance		
Marginal model of W	DUM = 0	1.948*
Marginal model of TB	DUM = 0	1.718*
Marginal model of GDP	DUM = 0	3.356***
Conditional model	DUM = 0	1.802*

***, ** and * indicates rejection of the null hypothesis at the 1%, 5% and 10% significance level, respectively.

4. Discussion and comments on policy implications

Analyzing agents' expectations and their behavior based on the expectations is essential in setting a credible and efficient central bank policy to manipulate economic activities. As such, our paper addresses an active policy debate while also addressing growing concern about the management of expectations by monetary authorities. We make use of the unconventional monetary policy tool of QE to probe the impact of QE on agents' behavior. In this regard, anchoring announced to the public appear as a crucial means of shaping the expectations. Yellen (2013) states that well-anchored inflation expectations have proven to be an immense asset in conducting monetary policy after the 2008 crisis. Recent studies stipulate that commitment of the FED to its pre-announced inflation rate and the resulting formation of expectations helped avoid the prolonged disinflationary process associated with the post-crisis high rates of unemployment (Ball & Mazumder, 2015). While adaptive/past-based expectations may be a reasonable premise in some circumstances, predictive monetary policy, transparent communication, and stable expectations play a crucial role, since they influence all sorts of behavior and may help avoid major instabilities predicted by standard modeling. Similarly, Trichet (2010) explains the use of anchoring as "First, the precise quantitative nature of our definition of the price stability objective has proved crucial in anchoring longer-term inflation expectations. And, as a result, it has protected us against both upside and downside risks to price stability, even in these most turbulent of times. The anchoring of private inflation expectations induces a self-correcting mechanism in response to temporary disturbances in price developments, thereby easing the burden on monetary policy."

Regarding the performance of economic agents in forming the expectations, the global financial crisis set the stage for realization of such expectations' success or failure, especially for the near future. We exemplify the expectations by two professionals and an institution with primary business of dealing with risk to assess the capability of even the most experienced professionals. In 2005, the FED former chairman, Alan Greenspan stated "Overall, while local economies may experience significant speculative price imbalances, a national severe price distortion (i.e. a housing bubble) seems most unlikely in the United States, given its size and diversity." The second professional is also a FED chairman, and a professor of macroeconomics with textbooks and influential papers published; Ben S. Bernanke stipulated "The risk that the economy has entered a substantial downturn appears to have diminished over the last month or so" in June 2008, only about three months before Lehman Brothers declared bankruptcy on September 15, 2008. The failure in the forecast of two of the most experienced professionals in the US validated the

importance of the unpredictable behavior of expectations, which necessitated further investigation. What Greenspan could not anticipate was the lowest price growth correlation jumping from −0.6 to 0.17, a historical unprecedented change. Bernanke's failure is reasoned by a much larger set of data that was somehow misinterpreted. In addition, the American International Group (AIG), the giant conglomerate specializing in insurance and risk taking, was not able to foresee the upcoming sudden fall of home prices before being filed for bankruptcy.

The ongoing pace of economic variables in their pleasing expected ranges should not make policy designers lose their alertness. As Mishkin (2011b) indicated "Up until August 2007, advances in both theory and empirical work in the study of monetary economics had led both academic economists and policymakers to argue that there was now a well-defined "science of monetary policy". There was a general consensus in central banks about most elements of monetary policy strategy, and monetary policy was perceived as being highly successful in OECD countries, with not only low inflation, but also low variability of inflation. In addition, output volatility had declined in these countries, and the period since the early 1980s was dubbed the "Great Moderation". Monetary economists and central bankers "were feeling pretty good about themselves." These were the descriptions of how monetary authorities felt right before the turmoil. Emergence of the macro prudential policy has to be emphasized toward efforts of detecting and preventing crises even before they become effective. Mishkin (2011a) recommends the use of macro prudential policy as "Macro-prudential regulations can be used to dampen the interaction between asset price bubbles and credit provision. Other macro-prudential policies to constrain credit bubbles include dynamic provisioning by banks; lower ceilings on loan-to-value ratios or higher haircut requirements for repo lending during credit expansions; and Pigouvian-type taxes on certain liabilities of financial institutions."

5. Conclusion

Economists agree on the fact that the shocks to the financial system resulting from the global financial crisis were in many ways more complicated compared to those triggered by the Great Depression of the 1930s, and yet, the consequent contraction of economic activity appeared to be less severe (Mishkin, 2011b). Although Taylor (2014) believes that post-crisis aggressive monetary policy was not as effective as expected, Mishkin (2011b) suggests it was the best tool that could be implemented to mitigate the shocks, since the severity of the crisis in 2008 overwhelmed the ability of conventional monetary policy to counteract it. Except for efficiency debates, the regime changes rekindled questions on the Lucas Critique that naturally arise in the environment of major policy shift.

Following the emergence of the LC, monetary models posed challenges in regard to their potency to explain/forecast inflation dynamics and as a policy tool, due to their inability to accurately capture the behavior of the agents after a shift. According to the main argument of Lucas, any change in the macroeconomic policy, such as QE in our case, will alter the expectations of the agents who make assessments by considering the future rather than the past and they will adapt their expectations and behavior to the new policy stance. Lucas stressed on the parameters of the econometric model that become unstable across different policy regimes. Monetary shifts such as the QE policy carry high possibility to alter the structure of past-data-based economic models, as foreshadowed in the LC. If the LC holds, it is deceptive to focus solely on the past when economic consequences of such policies are determined, whereby expectations play a significant role in shaping them. Indeed, the management of expectations about future policy has become a central element of monetary theory with zero-bound policies, as highlighted in Mishkin (2011b).

At the same time, the QE period represents an interesting and unique case of study. Our empirical estimates reject the condition of superexogeneity or parameter invariance, providing credibility to the LC. This is contrary to Hurn and Muscatelli (1992) which seems to be the only empirical paper that tests LC validity via superexogeneity methodology (in the example of the UK money demand over the period 1966Q4–1989Q4). Several other works (Bajo-Rubio et al., 2007; Estrella & Fuhrer, 2003; Leeper & Zha, 2003) generally found no or modest quantitative impact of LC in monetary relationships, while Rudebusch (2005) argues that the main reason why most of the studies fail to detect the LC is that shifts in the policy rule may be unimportant historically. Indeed, the QE period represents the opportunity of radical policy shifts capturing massive liquidity provisions, purchases of both government and private assets, and dramatic expansion of the FED's balance sheet. This might be one explanation for our results that significantly support the validity of the LC in the model of money demand in the US.

In the context of our findings, what policymakers should consider is how to deal with those parameter inconstancies and therefore, with expectations. The instability of monetary models in the presence of structural breaks (following regime shifts) would mean considerable challenge for their use as a policy tool. However, Bernanke (2009) suggests that expectations, if effectively monitored, can rather be used as an additional tool to manage the implications of policy changes, especially in the environment of zero-bound policy. As the former FED chairman Yellen (2013) stressed, management of expectations has proven to be an immense asset in conducting post-crisis policies and minimizing policies' potential costs to the economy.

The theoretical literature strongly supports expectation management to stimulate consumption during the zero-bound period because a commitment to maintain low short-term interest rates for a longer time triggers lower long-term interest rates and simultaneously raises inflation expectations, thereby reducing the real interest rates, and helping to continue zero-bound policies for a long period of time (Eggertsson & Woodford, 2003). With strong commitment, clear communication and broad guarantees, policymakers can actually get the agents to react more for new policies. Many of the actual programs implemented during the crisis had elements of guarantees, although they could use them more extensively (Caballero, 2010). The IMF (2013) stipulates that providing maximum clarity to the public about the expansionary policies (thereby anchoring long-term inflation expectations) helped the FED avoid prolonged deflation that started after the crisis, and at the same time, increase its flexibility to use securities purchases to provide additional accommodation. For instance, the rate of US core inflation[2] in 2011 was close to its level before 2008, despite the short-run prediction of the Phillips curve that high unemployment rates would drag inflation rates well below zero (Ball & Mazumder, 2015). The paper suggests that one of the reasons for this is that the Fed's commitment to a 2% inflation target has kept expected inflation near 2%, which in turn has prevented actual inflation from falling very far below that level.

The use of a monetary policy based on QE1-2-3, overall, was an accomplishment and helpful to mitigate destructive shocks by the financial system. The FED was largely successful in administering and even manipulating the expectations – as suggested by Lucas – and made use of drastic change in the monetary policy regime to keep the growth rate, as well as the unemployment rate, at desirable levels despite the disastrous magnitude of the global financial crisis. The trends in the US growth, unemployment and inflation rates provided in Table 3 and Fig. 2, in fact, support relative success of those combined policies.

[2] Core inflation – inflation, excluding the transitory effects of supply shocks.

Table 3
US real GDP growth, unemployment and inflation (Source: Federal Reserve Economic Data, FRED, https://fred.stlouisfed.org).

Year	GDP growth (annual %)	Unemployment (% of total labor force)	Inflation, GDP deflator (annual %)
2000	4.13	3.97	2.20
2001	1.00	4.74	2.20
2002	1.74	5.78	1.60
2003	2.86	5.99	1.90
2004	3.80	5.54	2.70
2005	3.51	5.08	3.10
2006	2.85	4.61	3.00
2007	1.88	4.62	2.70
2008	−0.14	5.80	1.90
2009	−2.54	9.28	0.80
2010	2.56	9.61	1.20
2011	1.55	8.93	2.10
2012	2.25	8.08	1.90
2013	1.84	7.36	1.80
2014	2.45	6.16	1.90
2015	2.88	5.28	1.10
2016	1.57	4.88	1.10
2017	2.22	4.35	1.90
2018	2.86	3.89	2.30

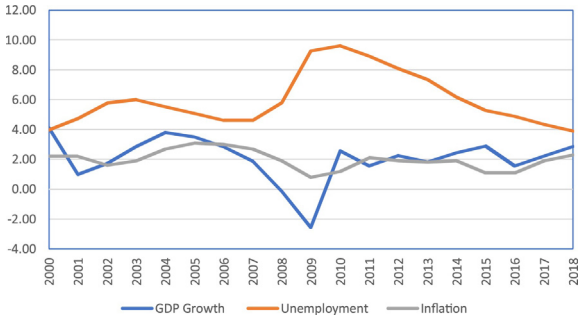

Fig. 2. Trends of US real GDP growth, unemployment and inflation (2000–2018).

Currently, central banks use models free from the LC. As indicated by Israel (2016), the Fed employs two DSGE models, which are revised and extended versions of the models presented in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007), respectively. Similarly, two of the most important models used by the ECB are the New Area White Model, based on Smets and Wouters (2003), and the CMR Model based on Christiano, Motto, and Rostagno (2010).

Another example of preparing and managing expectations can be observed in the gradual increase of interest rates with the first actual tightening in December 2015. The increase in the rates was sufficiently small and gradual, accompanied by prior effective communications with the public, having provided clear signals about future tightening. As a consequence, both domestic and international impacts were smooth, while relative depreciation of other currencies against the dollar had started well before the actual FED's tightening. This is largely due to the expectations

formed by the speeches of the FED chairpersons from 2013 about their intentions to gradually temper the QE regime.

As Bernanke (2009) mentioned, the FED prompted considerable effort in "developing a suite of tools to ensure that the exit from highly accommodative policies can be smoothly accomplished when appropriate, and FOMC participants have spoken publicly about these tools on numerous occasions". Given the existence of structural breaks and associated expectation changes documented by our results, a central bank commitment that firmly anchors long-run inflation expectations can make an important contribution to the effectiveness of its policies aimed at stabilizing and stimulating economic activity in the face of adverse demand shocks. The recommended acts would include continuing to actively review its communication strategy, and to make its outlook and policy intentions as clear as possible. The commitment to certain nominal anchors is not necessarily limited to inflation expectations, but also extends to other indicators such as money supply and exchange rate. Our evidence of the superexogeneity in this work compatibly highlights the crucial role of the management of expectations, seemingly shaped by the policy itself. Transparency, communication and credible commitment of the central banks have become important elements for successful monetary policy outcomes, which are truly possible under the condition of central bank independence.

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