8-2016

Essays on Monetary Policy Rules and Inflation Dynamics

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Essays on Monetary Policy Rules and Inflation Dynamics

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Economics

by

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August 2016
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Abstract

There has been a growing trend to utilize nonlinear models to analyze key issues in monetary policy and international macroeconomics. Using traditional linear models to understand nonlinear relationships can often lead to inaccurate inference and erroneous policy recommendations. The three essays in this dissertation explore nonlinearity in the Federal Reserve's policy response as well as between a country's inflation dynamics and integration in the global economy. My aim in accounting for potential nonlinearity is to get a better understanding of the policy makers' opportunistic approach to monetary policy and evaluate the inflation globalization hypothesis, which basically predicts that global factors will eventually replace the domestic determinants of inflation.

In the first essay I develop a broad nonlinear Taylor rule framework, in conjunction with real-time data, to examine the Fed's policy response during the Great Moderation. My flexible framework is also able to convincingly show that the Fed departed from the Taylor rule during key periods in the Great Moderation as well as in the recent financial crisis. The second essay uses a threshold methodology to investigate the importance of nonlinear effects in the analysis of the inflation globalization hypothesis. Finally the third essay investigates the relationship between inflation and globalization, under an open-economy Phillips Curve framework, for a panel of OECD countries with a dynamic panel GMM methodology. Contrary to most of the previous literature, which ignores such nonlinearities, my new approach provides some interesting empirical evidence supportive of the effect globalization has on a country's inflation dynamics.

Acknowledgements

I am deeply grateful to my dissertation committee chair, Andrea Civelli, for his continued guidance and support during my graduate studies. I owe profound thanks to my committee members, Jingping Gu and Tim Yeager, who helped improve my work and increased my research capabilities. Lastly, this dissertation and my academic studies would not be possible without the constant support and belief of my parents, Ahmad and Nausheen.

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1 Introduction

There has been a growing trend to utilize nonlinear models to analyze key issues in monetary policy and international macroeconomics. Using traditional linear models to understand nonlinear relationships can often lead to inaccurate inference and erroneous policy recommendations. The three essays in this dissertation explore nonlinearity in the Federal Reserve's policy response as well as between a country's inflation dynamics and integration in the global economy. My aim in accounting for potential nonlinearity is to get a better understanding of the policy makers' opportunistic approach to monetary policy and evaluate the inflation globalization hypothesis, which basically predicts that global factors will eventually replace the domestic determinants of inflation. The validity of the inflation globalization hypothesis could eventually lead to prominent changes in the conduct of monetary policy, so it is imperative to identify the exact role global forces play in the inflation process.

In the first essay, A multiple threshold analysis of the Fed's balancing act during the Great Moderation, I develop a broad nonlinear Taylor rule framework, in conjunction with real-time data, to examine the Fed's policy response during the Great Moderation. My analysis finds that standard two-regime smooth transition models are unable to fully capture the Fed's nonlinear response. I therefore utilize the Multiple Regime Smooth Transition model (MRSTAR) to get a better understanding of the Fed's asymmetric preferences and opportunistic conduct of monetary policy. With the MRSTAR model I am able to use both inflation and the output gap as concurrent threshold variables in the Fed's policy response function and am able to determine that policy makers prioritize loss of output over inflationary concerns. My flexible nonlinear framework is also able to convincingly show that the Fed departed from the Taylor rule during key periods in the Great Moderation as well as in the recent financial crisis.

The second essay, Globalization and inflation: A threshold investigation, uses a threshold methodology to investigate the importance of nonlinear effects in the analysis of the inflation globalization hypothesis. Accounting for potential nonlinearities in the Phillips Curve, I show that trade openness is not rejected as a threshold variable for the effects of domestic and foreign slack on inflation in many advanced economies, and also find a switch of the output gap slopes from one regime to the other that is consistent with the key predictions of the inflation globalization hypothesis. For some countries the threshold Phillips Curve model also leads to improvements in out-of-sample forecasts over the linear Phillips models, especially at longer horizons. Contrary to most of the previous literature, which ignores such nonlinearities, my new approach provides some interesting empirical evidence supportive of the effect globalization has on a country's inflation dynamics.

Finally the third essay, A dynamic panel threshold analysis of the inflation globalization hypothesis, investigates the relationship between inflation and globalization, under an open-economy Phillips Curve framework, for a panel of OECD countries with a dynamic panel GMM methodology. Previous studies on the inflation globalization hypothesis have examined this question primarily at the individual-country level. However, a panel approach seems quite appropriate as globalization measures, such as trade openness, often exhibit considerable cross-sectional variation. Using this framework, I find strong evidence in favor of including global factors, as captured by the foreign output gap, in a country's inflation process. I further augment the dynamic panel model with a threshold component and show that trade openness acts as a threshold variable for the effects of domestic and foreign slack on inflation. Importantly, the switch in the output gap slopes from one regime to the other is consistent with the key predictions of the inflation globalization hypothesis, so that in more open economies the foreign output gap replaces the domestic output gap as the key determinant in the country's domestic inflation process.

2 Chapter 1

A multiple threshold analysis of the Fed's balancing act during the Great Moderation

Abstract

Empirical evidence has generally shown that the Fed follows close to a Taylor rule in setting policy rates. This paper continues this line of inquiry by developing a broad nonlinear Taylor rule framework, in conjunction with real-time data, to examine the Fed's policy response during the Great Moderation. Our analysis finds that standard two-regime smooth transition models are unable to fully capture the Fed's nonlinear response. Thus we utilize the multiple-regime smooth transition model (MRSTAR) to get a better understanding of the Fed's asymmetric preferences and opportunistic conduct of monetary policy. With the MRSTAR model we can use both inflation and the output gap as concurrent threshold variables in the Fed's policy response function and are able to determine that policy makers prioritize loss of output over inflationary concerns. Our flexible nonlinear framework is also able to convincingly show that the Fed departed from the Taylor rule during key periods in the Great Moderation as well as in the recent financial crisis.

2.1 Introduction

For over 20 years the Taylor rule (Taylor, 1993) has been used to both shape and evaluate the central bank's policy actions. An important feature of the rule was that it allowed the nominal policy rate to respond to both inflation and the output gap, reflecting the twin concerns of monetary authorities. While Taylor intended his rule to be normative, the fact that it was also a good match with the Fed's interest-rate setting behavior increased its appeal as a tool to conduct historical policy analysis (Asso and Leeson, 2012).

Figure 1 plots the recommended rates from the Taylor rule alongside the historical Fed Funds rate and we continue to see the Fed generally being close to the Taylor rule when setting the policy rates. In the course of time, a few modifications have been further made to the original Taylor rule to better fit the Fed's policy response. First there is strong indication that policy makers are forward-looking so that expectations of inflation and the output gap play a greater role than current or lagged values in setting interest rates (Clarida et al., 2000). An interest-rate smoothing term was also added because in practice the Fed prefers to change its policy rate gradually to account for the uncertainty in its economic models (Blinder and Reis, 2005). Moreover, a focus was put on looking at the real-time data that is actually available to the policy makers at the time of their decision (Orphanides, 2001). Finally, the possibility of the Fed's policy rule being nonlinear has also been examined (Kim et al., 2005 and Hayat and Mishra, 2010).

We continue this line of inquiry by developing a broad nonlinear Taylor rule framework to examine the Fed's policy response during the Great Moderation, an era in which the U.S. economy experienced low output volatility and relatively mild inflation (Ahmed et al., 2004). Purported changes in the Fed's conduct of monetary policy and the role they played in the

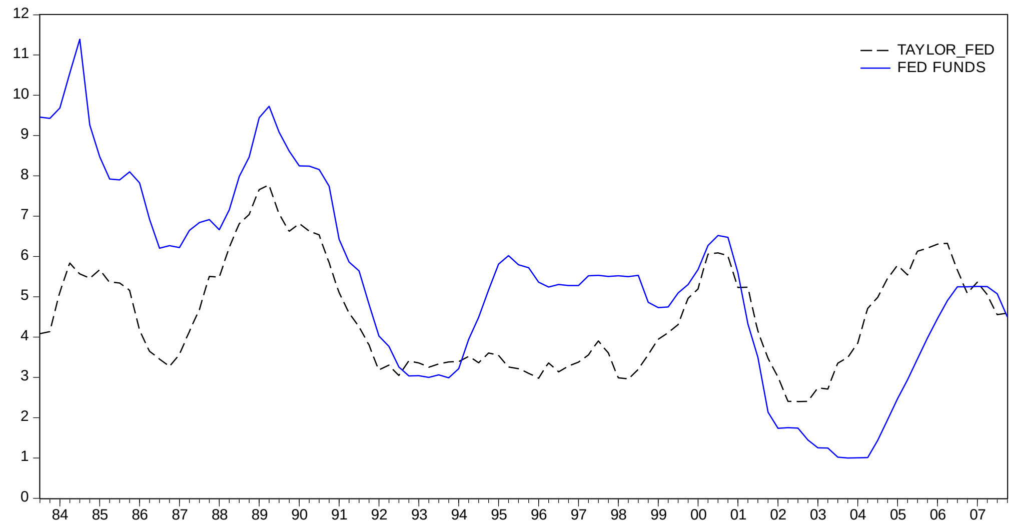

Figure 1: Actual Fed Funds rate and the rates under the classic Taylor Rule (Taylor, 1993).

Great Moderation have been especially analyzed and debated.[1] Boivin and Giannoni (2006) show that the Fed, by being more responsive to inflation, was able to significantly reduce the volatility of both U.S. output and inflation levels.[2] Bernanke (2012) further contends that the Fed also helped increase economic stability by reducing the potency of exogenous shocks. Our goal then is to compare a broad set of non-linear reponse functions, in conjunction with real-time data, to get a better understanding of how the Fed successfully balanced its dual-mandate during this significant economic period. We can then determine if the improved monetary performance was indeed driven by a greater emphasis on policy rules as suggested by Taylor (2012). While it is understandable that much of the recent focus has been on the Fed's unconventional response following the financial crisis, historical analysis is still valuable as long as we can clearly identify the policies in place when the times were good.

[1]See for example Favero and Rovelli (2003), Primiceri (2005), Sims and Zha (2006), Bianchi (2013) among many others.

[2]Stock and Watson (2003) determined that better monetary policy contributed up to 25% of the decline in output volatility. Improved monetary policy was also seen as a key factor in lower output volatility for the G7 countries (Summers, 2005).

Our nonlinear analysis is based on the Smooth Transition Autoregressive (STAR) methodology (Teräsvirta, 1994), which provides a flexible framework to test whether the Fed has asymmetric preferences and whether it conducts policy in an opportunistic manner. By allowing for a smooth transition between regimes, the STAR models make it easier to identify gradual policy changes and so have been a popular choice to capture nonlinear monetary policy response functions. However one concern with the current empirical literature is the reliance of only one threshold variable to generate the nonlinearity such as inflation as in Martin and Milas, 2010 and Lamarche and Koustasy, 2012, output as in Alcidi et al. (2011) and Kazanas et al. (2011) or some other macroeconomic variable like financial stress as in Gnabo and Moccero (2013). Such a modelling approach forces one factor to be completely responsible for the observed nonlinearity in the policy response function. In order to overcome this limitation, we also employ the Multiple Regime STAR (MRSTAR) model as proposed by Dijk and Franses (1999) in our nonlinear analysis. Thus an important contribution of our empirical strategy is that with the MRSTAR model both inflation and the output gap are able to act as simultaneous thresholds in the Fed's response function. With four distinct regimes, the MRSTAR model is able to give a more complete overview of the various economic scenarios and contingencies the Fed faces when setting the policy rate and so represents a better tool for understanding key policy decisions.

Using the STAR methodology, we estimate Taylor rules with real-time data for the years 1983-2007. Our first nonlinear Taylor model has a Logistic STAR1 specification in which the Fed's forecast for the output gap acts as the threshold variable responsible for the regime switch.[3] In the *Normal* regime (output gap greater than -1.66%) the Fed's response is in line with the Taylor rule with an inflation coefficient greater than 1 and a positive output gap coefficient. However, the Taylor rule fails to capture the drastic drop in the Fed Funds

[3] A monetary policy regime switch is said to occur only if there is a systematic change in the policy response.

Rate seen in the *Distressed* regime (output gap lower than -1.66%). Notably, the *Distressed* regime corresponds to periods with strong economic shocks such as the Savings and Loans crisis in 1987, the recession in the early 90s and the dot-com crash in the 2000. We then estimate a Logistic STAR2 model in which the forecast of inflation acts as the threshold variable. We find that while the Fed does have a strong response to inflation in the *Outer* regime (inflation either below 1.6% or above 3.1%), it reacts only to the output gap in the *Inner* regime (inflation between 1.6% and 3.1%). So we continue to see evidence of the Fed being opportunistic in trying to achieve its inflation objective (Orphanides and Wilcox, 2002).

Extensive misspecification tests reveal that nonlinearity remains unmapped by these Logistic STAR models. We then turn toward the MRSTAR model, which combines the separate regimes of the LSTAR1 and LSTAR2 specifications and so allows the Fed to have a different response in each of these economic regimes. We find that the Fed follows the Taylor rule only in the *Normal & Outer* regime of the MRSTAR model. In the *Normal & Inner* regime the Fed has a very passive response, while in the *Distressed & Outer* and *Distressed & Inner* regime the Fed's response to inflation is less than 1 and so in clear violation of the *Taylor Principle*. These findings clearly show that the Fed did depart from the Taylor rule for key periods in the Great Moderation. From these estimated responses we can also determine that the Fed prioritizes a loss of output over inflationary concerns, and thus propose a loss function that can account for such asymmetric preferences. Finally we also show that the MRSTAR model can be used to examine the Fed's response during the financial crisis.

The rest of the paper is organized as follows. Section 2.2 reviews the literature on nonlinear Taylor rules. Section 2.3 describes the real-time data sources. Section 2.4 gives the empirical methodology and the Taylor rule specifications. Section 2.5 discusses the main findings while Section 2.6 concludes.

2.2 Literature Review

Widespread policy failures in the 1970s pushed the Fed and other central banks to undergo significant institutional reforms so that monetary policy could be conducted in a more systematic and transparent manner (Issing, 2008). Policy rules in this environment became particularly attractive as a means to codify the decision making process (Poole, 1999). The simplicity of the Taylor rule along with its emphasis on short-term interest rates enabled it to quickly gain traction with central bankers (Kahn, 2012).

The classic Taylor rule can be expressed as

$$i_t = r^* + \pi_t + \zeta_\pi(\pi_t - \pi^*) + \zeta_y y_t \tag{1}$$

where i_t stands for the policy rate in the period t, r^* is the long run real equilibrium interest rate, π_t and π^* represent the current and target rates of inflation, and y_t is the output gap. Taylor suggested the value of 0.5 for both the response parameters while r^* and π^* were set at 2%. Notably the Taylor rule with these parameter values ensures that the central bank changes the nominal interest rates by more than one-for-one to any deviations of inflation from the target. This has been referred to as the *Taylor Principle* and is seen as a way for central banks to keep inflation low and stable in the long run (Walsh, 2006).

Clarida et al. (2000) showed that a linear Taylor-type rule is in fact an optimal policy response in a dynamic New Keynesian model with sticky prices. However, a key requirement is for central banks to have a quadratic loss function so that they give equal weight to positive and negative deviations of inflation and the output gap from their intended targets. Policy observors considered this loss function unrealistic, leading them to an examination of asymmetric preferences for policy makers. Cukierman and Gerlach (2003) suggested a piecewise quadratic loss function such that policy makers have the standard quadratic specification when the output gap is negative but focus only on inflation when the output gap is positive (actual output greater than potential). A more general specification for such a loss function is given in Bec et al. (2002) as

$$L(\pi_t, y_t) = \frac{1}{2}\left\{(\pi_t - \pi^*)^2 + w_e y_t^2\right\} I_{[y_t>0]} + \frac{1}{2}\left\{(\pi_t - \pi^*)^2 + w_r y_t^2\right\} I_{[y_t<0]} \tag{2}$$

where $I[.]$ is indicator function and w_e, w_r are the positive relative weights to output stabilization objective (so $w_e = 0$ in the original Cukierman and Gerlach (2003) loss function). Loss functions that capture asymmetric preferences make it optimal for the central banks to have a nonlinear response to existing economic conditions.[4]

Nonlinearity in the response function can also arise if policy makers try to take advantage of underlying economic conditions to achieve policy goals. Orphanides and Wilcox (2002) examine the possibility that policy makers are opportunistic and only respond to inflation when it is outside some target range. So when inflation is within this range, policy makers do not actively try to bring inflation toward the desired target and instead react only to shocks that move inflation further away from the target. In such a setting the policy focuses on output when inflation is moderate but moves toward price stability as inflation becomes either too high or too low.[5]

A number of different strategies have been used to model the central bank's nonlinear response. A popular approach has been to allow policy makers to vary their response from one

[4]Dolado et al. (2004) and Surico (2007) find evidence of the Fed having asymmetric preferences. Asymmetric preferences and nonlinear policy responses have also been observed for the Bank of Canada (Komlan, 2013), the Bank of England (Brüggemann and Riedel, 2011) and the South African Reserve Bank (Baaziz et al., 2013) as well.

[5]Aksoy et al. (2006) find that an opportunistic policy rule is effective in achieving disinflation and at a much lower cost than standard linear rules.

regime to another. If the regime switch depends on the value of some observed economic variable, then we can apply threshold models such as the Threshold Autoregresive (TAR) model or the STAR model. Alternatively the regime switch can occur due to an unobserved state variable and modeled as a Markov Switching (MS) process (Bae et al., 2012). While this approach requires fewer prior assumptions for the switch and so is more data driven, it also makes it harder to infer the exact economic circumstances that are generating the nonlinear response.[6] Given that central banks often have clear policy objectives, it is highly likely that shifts in the policy response are a direct reaction to observed changes in economic conditions. The STAR model is also convenient for modelling gradual changes in responses as policy makers are generally wary of abrupt policy changes as it can lead to higher volatility in financial markets and cause the public to lose confidence in the central bank's ability to manage the economy (Blinder and Reis, 2005). Thus in our analysis, we will employ the STAR methodology to determine if the Fed's monetary policy changed in response to key macreconomic variables during the Great Moderation.[7]

A limitation with both TAR and STAR models is that they rely on only one threshold variable to generate the nonlinearity. In the context of monetary policy analysis, this often leads one economic factor to be completely responsible for the central bank's nonlinear response function. Indeed Kim et al. (2005) have shown that in the case of the Fed, the nonlinearity is best captured when the interaction of the output gap and inflation is included in the standard Taylor rule specification. Thus we also consider the more flexible MRSTAR model and in doing so allow both inflation and the output gap to act as concurrent threshold variables in the Fed's response function.

[6]This is also an issue in the context of Time-Varying Parameter models that have been also used to identify the central bank's nonlinear response. See Boivin (2005) and Kim and Nelson (2006) for examples of this empirical framework.

[7]Gregoriou and Kontonikas (2009) have also shown that the STAR model outperforms the Markov Switching model in out-of-sample interest rate forecasts for key OECD countries.

To our knowledge, Bunzel and Enders (2010) is the only other work that also allows both inflation and the output gap to have nonlinear effects on the Fed's policy response. However there are three strong differences as it relates to the empirical analysis in this paper. First, even when they consider both inflation and output gap as thresholds, it is still in the context of a traditional two-regime model. Thus in their framework the Fed can only be policy active if there is either a negative output gap or if inflation is above an interim target π_t^* (the average inflation rate in the last two years) and so forces the same policy response in periods with high inflation as in periods of recession.[8] Second, their Taylor rule specifications are based on the current horizon and so are unable to capture the forward-looking behavior of policy makers as we do with our models using the Fed's own real-time forecasts as inputs. Finally they use the TAR framework in their analysis which, unlike the STAR models, is only able to identify sharp changes in policy. Within the STAR framework we are also able to use the non-linearity specification tests, as described in Dijk and Frances (1999), to explicitly determine if the STAR model is adequate to capture the non-linear response. Such a feature is missing in standard TAR analysis of monetary policy rules.

2.3 Data

The Great Moderation is generally considered to have begun sometime in the early to middle '80s (Summers, 2005). Thus our analysis for this era is based on U.S. quarterly data for the periods 1983:Q3 to 2007:Q4. We use 1983:Q3 as our starting range as it comes after the sustained disinflation push that had been adopted by the Volcker Fed. Further, early in the Volcker era there was a greater focus on monetary aggregates and so the Taylor rule applied to such monetary regimes can often lead to misleading analysis (Sims and Zha,

[8] It is also a little unclear if the threshold values in these 'opportunistic' Taylor rule models are actually based on grid search estimates or are taken as ad hoc, yet reasonable conjecture of when policy makers should be reacting to output and inflation.

2006). Ending at 2007:Q4 avoids the financial crisis, during which the Fed took a number of unconventional monetary measures (Cecchetti, 2009) that can be difficult to analyze in a Taylor rule framework.

In much of the early literature the empirical analysis on Taylor rules was done using *expost* data that had generally undergone significant revisions. Orphanides (2001) contends that it's better to use the real-time data that was actually available to policy makers because Taylor rule prescriptions can vary substantially depending on the type of data that is used in the analysis. Thus we rely only on real-time data sources.

Our first source of real-time data comes from the Greenbooks that the Fed staff specifically prepared for the FOMC meetings. The Greenbooks contain the Fed's latest information on previous output and inflation levels as well as projected forecasts for different time horizons. In our analysis, we will be using primarily the GDP deflator as the measure of the price level so that the forecasts of inflation are just the Greenbook-projected quarter-over-quarter (*annualized*) changes in the GDP deflator. Since the policy rate is not revised we just use the annualized effective Fed Funds rate series from the St. Louis Fed (FRED) database.[9]

We also use the data set at the Federal Reserve of Philadelphia as another source of real-time data. Croushore and Stark (2001) have created data vintages for key macroeconomic series where a vintage is defined as the data that is actually available in a particular quarter. Each vintage incorporates revisions to earlier observations, so we can obtain the real-time values of real GDP and the GDP deflator. A quadratic detrend is then applied on the real GDP series to get the real-time output gap estimates for this data source.[10] We will be using this data as a robustness check for the Taylor rules estimated with the Greenbook forecasts.

[9]Unit root tests provided in Appendix A and little evidence of any non-stationary process.

[10]Note per Orphanides and Van Norden (2002), real-time output gaps constructed by detrending are not reliable estimates of the actual output gap for a given period and so are used only to gauge the pressures policy makers were facing in real-time.

Figures 2 and 3 plot the output gap and inflation from the real-time data sources. To ease comparison we also include the *expost* series using the most recent revised data available. As can be seen the output gap forecast series from the Fed Greenbook (*fgap*) is closer to the revised series (*exgap*) than the detrended real-time output series (*rgap*). Nevertheless the forecasts of the output gap do diverge from the revised series notably in recessions and will result in different estimates of the Taylor rule (Molodtsova et al., 2008).

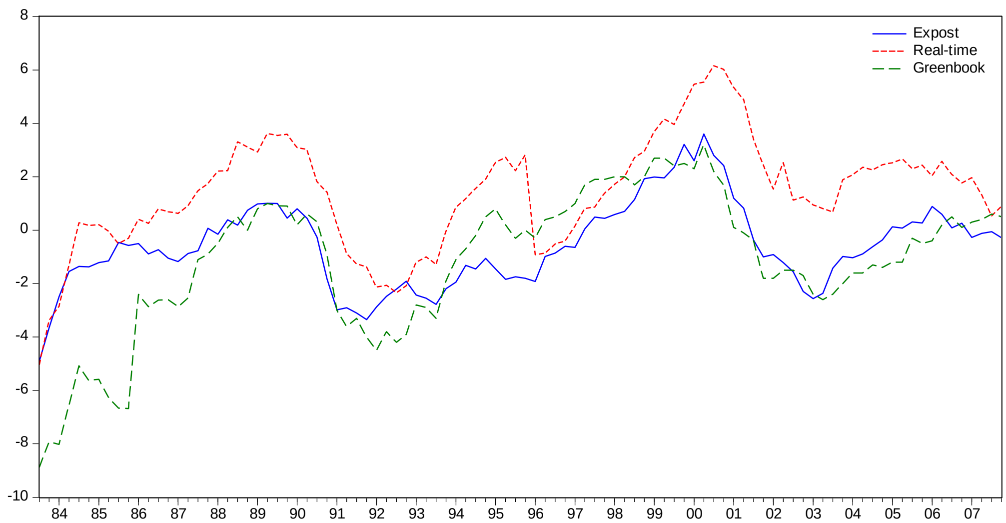

Figure 2: US output gap estimates based on either expost, real-time or Greenbook data.

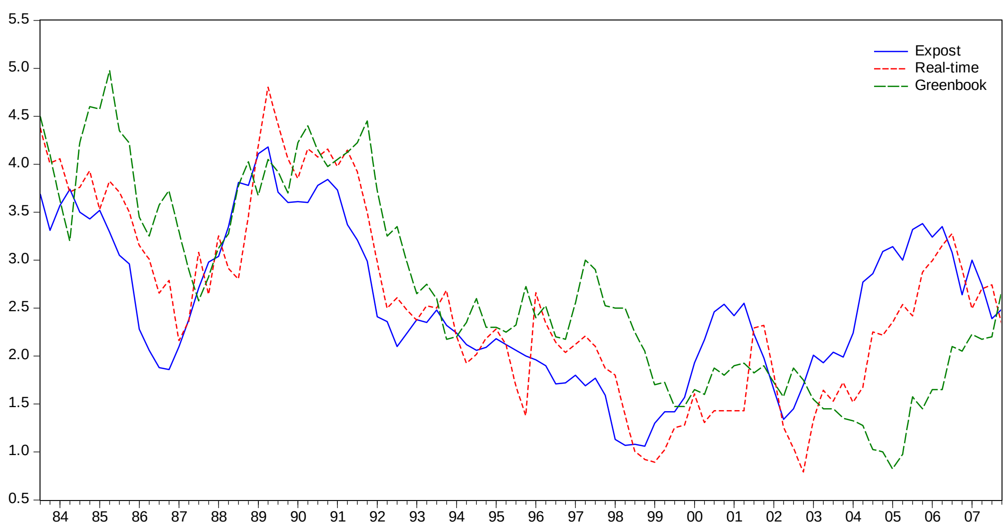

Figure 3: US inflation estimates (the year to year change in the GDP deflator)using either expost, real-time or Greenbook data.

2.4 Empirical Strategy

An advantage of Greenbook forecast data is that forward-looking Taylor rules can be easily estimated without any instrument variable.[11] Since our nonlinear analyis is based on the STAR model, we next give a brief overview of its modelling framework.[12]

2.4.1 STAR Methodology

The STAR model was developed as an extension of the traditional TAR models with the idea that there was a smooth transition between regimes. This feature makes the STAR convenient for modelling economic environments that undergo gradual changes. For a univariate time series y_t a STAR model can be specified as:

$$y_t = \theta_1' x_t \left(1 - G(s_t; \gamma, c)\right) + \theta_2' x_t G(s_t; \gamma, c) + \varepsilon_t \tag{3}$$

where $x_t = (y_{t-1}, ...y_{t-p}, z_{1t}, ...z_{kt})$ contains both lagged terms and other explanatory variables. The error term ε_t is a Martingale Difference Sequence with constant conditional variance. The transition function $G(.)$ is a continuous function that is bounded between 0 and 1 while s_t acts as the transition variable. So the STAR can be considered a regime-switching model where regimes are represented by the extreme points of $G(.)$ and there is a smooth transition from one regime to the other.

The choice of the transition function $G(.)$ plays an important role in determining the regime-

[11]These forecasts are assumed to be uncorrelated with current policy shocks (Boivin, 2006).
[12]This discussion borrows from Dijk et al. (2002) and Teräsvirta et al. (2010).

switching behavior. The logistic function has been commonly used so that:

$$G(s_t;\gamma,c) = \left\{1 + exp\left[-\gamma \prod_{k=1}^{n}(s_t - c_k)\right]\right\}^{-1} \tag{4}$$

with γ as the smoothness parameter, $c_1 \leq c_2 ... \leq c_n$ the threshold values that cause the switch between the two regimes. When $n = 1$ we get the Logistic STAR1 (LSTAR1) model and the two regimes are associated with small and large values of s_t relative to c_1. When $n = 2$ we get the Logistic STAR2 (LSTAR2) model with a regime switch when the transition variable goes below $c_1$or above c_2. Finally we can have the Exponential STAR (ESTAR) case where the exponential function is used as the transition function instead.

A key step in the STAR modelling framework is the hypothesis test of linearity against the LSTAR and the ESTAR cases. The null in this case is $\theta_1 = \theta_2$ with γ and c being unidentified nuisance parameters. In the context of STAR models a solution is to replace $G(.)$ with a suitable Taylor series approximation and then use a Lagrange Multiplier (LM) test to determine nonlinearity.

Estimation of the STAR models is generally performed by NLS, with one popular approach being the concentration of the sum of squares function to reduce the estimation complexity. If γ and c are held fixed, then the STAR model becomes linear in the parameters and can be estimated by OLS. Sensible starting values for γ and c are obtained by a two-dimensional grid search with γ usually made scale-free by dividing with the sample standard deviation of s_t. The grid values for c are also usually restricted to be within a subset of s_t so that there are enough observations in each regime.

To accommodate multiple regimes, Dijk and Franses (1999) also develop a Multiple-Regime STAR (MRSTAR) model by encapsulating two LSTAR models and so is useful in modeling more complex nonlinear process.

The MRSTAR model is expressed as:

$$y_t = \left[\theta_1' x_t \left(1 - G_1\left(s_{1t};\gamma_1,c_1\right)\right) + \theta_2' x_t G_1\left(s_{1t};\gamma_1,c_1\right)\right]\left[1 - G_2\left(s_{2t};\gamma_2,c_2\right)\right] \qquad (5)$$
$$+ \left[\theta_3' x_t \left(1 - G_1\left(s_{1t};\gamma_1,c_1\right)\right) + \theta_4' x_t G_1\left(s_{1t};\gamma_1,c_1\right)\right]\left[G_2\left(s_{2t};\gamma_2,c_2\right)\right] + \varepsilon_t$$

where $G_1(.)$ and $G_2(.)$ are logistic functions varying between 0 and 1.

2.4.2 Taylor rule specifications

I. Forecast Taylor Rule:

$$i_t = \rho i_{t-1} + (1-\rho)(\theta_0 + \theta_\pi E_t\pi_{t+k} + \theta_y E_t y_{t+h}) + \varepsilon_t \qquad (6)$$

We begin our empirical analysis by modifying (1) to get a forecast-based Taylor rule which serves as our baseline linear specification. The inflation response is now given by $\theta_\pi =(1+\zeta_\pi)$ while the intercept is $\theta_0 = r^* - \zeta_\pi\pi^*$.[13] We also as standard include an interest-rate smoothing parameter in the linear Taylor rule. Rudebusch (2006) has raised the concern that the smoothing preference found in estimated Taylor rules is often the result of the error term being serially correlated. Mehra and Minton (2007) however, showed that the smoothing term while smaller remained significant even after accounting for serial correlation. The main explanatory variables, $E_t\pi_{t+k}$ and $E_t y_{t+h}$, are the Fed's respective forecasts of inflation and the output gap with $k = 1$ (the one-quarter ahead inflation forecast) and $h = 0$ (within-quarter output gap forecast). For longer horizons we also use $k = 4$ (average of the $k = 1, 2, 3\, and\, 4$ forecasts).

[13]Convention is to take r^* as constant (usually the average real interest rate) and use it to determine the inflation target π^*.

II. LSTAR1 Taylor rule:

$$\begin{aligned} i_t =& \{[a_1 i_{t-1} + (1-a_1)(a_0 + a_2 E_t \pi_{t+4} + a_3 E_t y_t)](1-G(.)) \\ &+ [B_1 i_{t-1} + (1-B_1)(B_0 + B_2 E_t \pi_{t+4} + B_3 E_t y_t)](G(.))\} + \varepsilon_t \\ & with \;\; G(.) = \{1 + exp[-\gamma_1 (s_t - c_1)]\}^{-1} \end{aligned} \tag{7}$$

Our nonlinear specifications are based on the forecast Taylor rule in (6). We first look at the LSTAR1 case where the output gap forecast ($s_t = E_t y_t$) acts as the threshold variable. So when $E_t y_t > c_1$we have the *Normal* regime and when $E_t y_t < c_1$ we get the *Distressed* regime.

III. LSTAR2 Taylor rule:

$$\begin{aligned} f_t =& \{[a_1 i_{t-1} + (1-a_1)(a_0 + a_2 E_t \pi_{t+4} + a_3 E_t y_t)](1-H(.)) \\ &+ [B_1 i_{t-1} + (1-B_1)(B_0 + B_2 E_t \pi_{t+4} + B_3 E_t y_t)](H(.))\} + \varepsilon_t \\ & with \;\; H(.) = \{1 + exp[-\gamma_2 (s_t - c_2)(s_t - c_3)]\}^{-1} \end{aligned} \tag{8}$$

The next case looks at the LSTAR2 where the inflation forecast ($s_t = E_t \pi_{t+4}$) serves as the threshold variable. As in Taylor and Davradakis (2006), we prefer to take the threshold variable as just inflation rather than inflation relative to some assumed policy target, which simplifies the estimation and gives the Fed's target range for inflation. The LSTAR2 model also has two regimes: the *Inner* regime when $c_2 < E_t \pi_{t+4} < c_3$, and the *Outer* regime when either $E_t \pi_{t+4} < c_2 \, or \, E_t \pi_{t+4} > c_3$, with the Fed's response in the outer regimes restricted to be the same. Lamarche and Koustasy (2012) have shown that for forecast-based Taylor rules a two-regime model cannot be rejected in favor of a three-regime model, with a different response when $E_t \pi_{t+4} < c_2$ then when $E_t \pi_{t+4} > c_3$, and thus the LSTAR2 is appropriate for the Fed's nonlinear response.

IV. MRSTAR Taylor rule:

$$
\begin{aligned}
i_t = & \{[a_1 i_{t-1} + (1 - a_1)(a_0 + a_2 E_t \pi_{t+4} + a_3 E_t y_t)](H(.)) \\
& + [B_1 i_{t-1} + (1 - B_1)(B_0 + B_2 E_t \pi_{t+4} + B_3 E_t y_t)](1 - H(.))\}[G(.)] \\
& + \{[p_1 i_{t-1} + (1 - p_1)(p_0 + p_2 E_t \pi_{t+4} + p_3 E_t y_t)](H(.)) \\
& + [q_1 i_{t-1} + (1 - q_1)(q_0 + q_2 E_t \pi_{t+4} + q_3 E_t y_t)](1 - H(.))\}[1 - G(.)] + \varepsilon_t \\
& with\ G(.)\ and\ H(.)\ are\ as\ before
\end{aligned} \tag{9}
$$

Finally we consider the MRSTAR specification where forecasts for both inflation and the output gap are used as thresholds. The resulting model has four regimes by combining the regimes of the LSTAR1 and LSTAR2 specifications. The MRSTAR model thus allows for a more comprehensive policy response and should provide a better understanding of how the Fed balances its dual objective of keeping prices stable and output close to the economy's long-run potential.

2.5 Key Findings

2.5.1 Linear Taylor rules

Table 1 gives the estimates of the linear Taylor rule during the Great Moderation. We first estimate the forecast-based Taylor rule in (6) using two time horizons for expected inflation, $E_t\pi_{t+1}$(one quarter ahead) and $E_t\pi_{t+4}$(one year ahead). Due to data limitations we are able to only use $E_t y_t$ (current-quarter output gap forecast) in these specifications. For both horizons the coefficient for inflation is highly significant and positive (2.14 in specification *FT1* and 2.57 in *FT2*). A value greater than 1 shows that policy makers are following the *Taylor Principle* by responding strongly to inflation. From the estimated θ_0 in *FT2*, we determine that the Fed had an implicit inflation target of $\pi^* = 2.49\%$ during this period.[14] Previous research has also shown that the Fed since the Volcker era has had an implicit inflation target close to around 2.5% (Favero and Rovelli, 2003). Finally there is a view that the Fed especially during the Greenspan years focused more on the core CPI rather than the GDP deflator (Mehra and Minton, 2007). So *FT3* uses the one-year-ahead forecast of core CPI as the inflation variable, and we find little quantitative difference in the estimated coefficients. Overall the *FT2* specification gives the best fit in terms of the AIC and SBC criteria, indicating that policy makers consider a longer time horizon in their decision making process. This is in line with Amato and Laubach (1999) findings that a monetary policy focused on targeting inflation over longer horizons has significantly lower welfare costs than a policy that tries to stabilize current inflation.

We next augment (6) with the Fed's forecast for the growth in real output. As in Orphanides (2003), this is captured by the one-year-ahead output growth forecast relative to the potential output. From Table 1 we observe that while the Fed has a positive response to the output gap growth term in *FGT*, this variable is not significant at the10% level.[15] We then examine a Taylor rule that includes a proxy for the level of financial stress in the economy.

For the measure of financial stress, we consider both the IMF Financial Stress Index (FSI) as well as the Chicago Board Options Exchange's volatility index VXO. These indexes have also been used in Martin and Milas (2012) and Gnabo and Moccero (2013) respectively. Figure 4 shows these two measures are strongly corellated over this period. We see that the Fed's response has the correct negative sign but is highly insignificant in *FST* (see similar results when the VXO index is used instead). Thus there is not much evidence of the Fed actively responding to financial stress during the Great Moderation. Finally the

[14] $\pi^* = \frac{r^* - \theta_0}{\zeta_\pi}$ where $r^* = 2.85\%$ (the average real Fed Funds rate over this period).

[15] We also consider specification: $i_t = \rho i_{t-1} + (1-\rho)(\theta_0 + \theta_\pi E_t \pi_{t+3} + \theta_{\triangle y} E_t \triangle y_{t+3} + \theta_y E_t y_{t-1})$ used in Orphanides (2003) and saw simillar results.

last column in Table 1 gives the estimates of (6) using *expost* values of inflation and output gap. The coefficients are fairly similar to the forecast-based Taylor rules except for a much larger output gap response, which is not surprising considering that output undergoes more significant revisions over time.

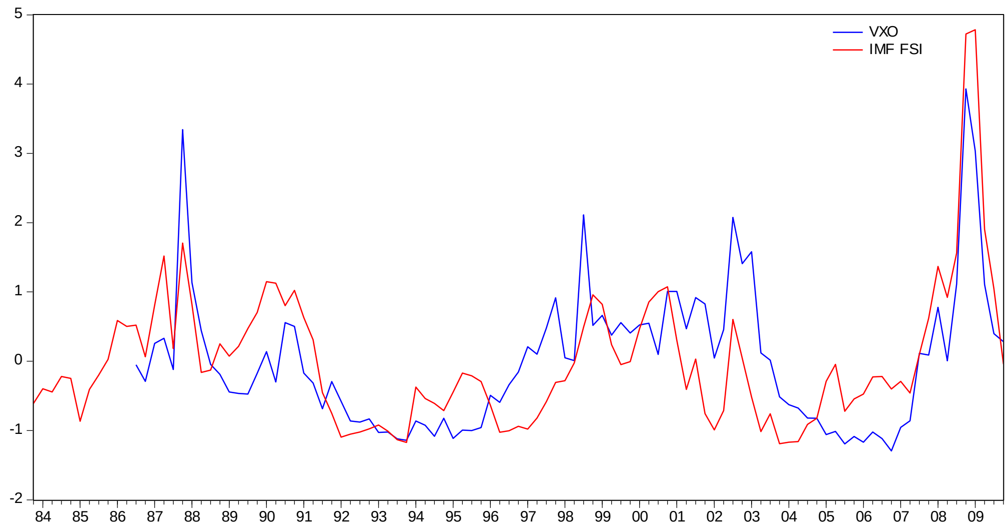

Figure 4: Level of financial stress in the US as given by the IMF Finacial Stress and the CBOE VXO indexes.

Table 2 provides several misspecification and diagnostic tests for the linear Taylor specifications *FT2, FGT* and *FST* in Table 1. LM type tests as suggested in Eitrheim and Teräsvirta (1996) are used to detect issues of nonlinearity and parameter constancy. The main candidates for threshold variables are the forecasts of inflation ($E_t\pi_t$ and $E_t\pi_{t+4}$) and the output gap (y_{t-1} and E_ty_t) along with the lagged Fed Funds rate as considered inQin and Enders 2008. We also use our measures of financial stress as threshold variables since there is some evidence that financial conditions can also lead to regime changes (Alcidi et al., 2011; Gnabo and Moccero, 2013). The p-values from the F-test (preferred for small samples) indicate that the assumption of linearity is indeed a strong restriction on the Fed's policy response. The strongest rejection, though, is seen from the Taylor rule variables and indicates their importance in the Fed's nonlinear response. We see mix evidence for the financial stress variables with the IMF FSI but not the VXO index rejecting the null of linearity. Further the forecasts of inflation and output gap remain highly significant as threshold variables for *FGT* and *FST* and so incorporating these additional explanatory variables is not enough to capture the Fed's non-linear response. Finally the LM tests for parameter constancy (Lütkepohl et al., 1999) show that there might be issues with stability as well.

Table 3 showed that both $E_t\pi_{t+4}$ and $E_t y_t$ can serve as the threshold variable for the *FT2* specification in the LSTAR framework. We then follow Teräsvirta (1994) and use his short test sequence to identify the correct model specification (LSTAR1 versus LSTAR2/ESTAR). The test sequence is given as $H_3 : B_3 = 0$, $H_2 : B_2 = 0|B_3 = 0$ and $H_1 : B_1 = 0|B_2 = B_3 = 0$ done on the auxiliary regression.[16] If H_2 yields the strongest rejection, then the LSTAR2 or ESTAR model should be selected; otherwise the LSTAR1 is the more appropriate model. Table 3 indicates that the LSTAR1 is the more suitable model when $E_t y_t$ is taken as the threshold variable. On the other hand, the LSTAR2 seems to be a better choice when $E_t\pi_{t+4}$ is taken as the threshold variable. So we have two distinct LSTAR specifications for the Fed's response depending on the choice of the threshold variable.

[16]This is simply $y_t = B_0^{'} x_t + \sum_{j=1}^{3} B_j^{'} x_t s_t^j + v_t^*$where $v_t^*$is the remainder term from the third-order Taylor explansion.

Table 1: **Linear Taylor Rules Estimates.** Sample period 1983-2007 (quarterly observations). All coefficient estimates are the long run responses as in Taylor (1993). CT uses expost data while all remaining use forecasts from the Greenbook dataset.

Equation	FT1	FT2	FT3	FGT	FST	CT
i_{t-1}	0.92***	0.83***	0.85***	0.84***	0.84***	0.93***
	(0.03)	(0.04)	(0.04)	(0.05)	(0.05)	(0.03)
$Constant$	0.02	-1.06	-1.83	-1.47	-1.55	-1.74
	(2.39)	(0.36)	(1.44)	(1.49)	(1.41)	(3.75)
$E_t y_t$	0.56	0.42**	0.40*	0.61*	0.49**	1.20**
	(0.39)	(0.19)	(0.20)	(0.33)	(0.22)	(0.59)
$E_t \pi_t$	2.14**					2.86**
	(0.92)					(1.51)
$E_t \pi_{t+4}$		2.57***		2.78***	2.74***	
		(0.46)		(0.63)	(0.52)	
$E_t \pi^c_{t+4}$			2.34***			
			(0.45)			
$E_t(y_{t+4} - y_t)$				0.77		
				(1.06)		
Str_t					-0.13	
					(0.22)	
Observations	98	98	98	98	98	98
RMSE	0.51	0.48	0.48	0.47	0.48	0.50
AIC	1.52	1.39	1.42	1.40	1.41	1.49
SBC	1.62	1.50	1.53	1.54	1.54	1.59

Standard errors robust to heteroskedasticty and serial correlation.

***, **,* significant at 0.10, 0.05 and 0.01 level.

Table 2: **P-values of misspecification tests**

(a) LM test of no autocorrelation

Lags	4	6	8
FT2	0	0	0
FGT	0	0	0
FST	0	0	0

(b) LM test of no ARCH

Lags	4	6	8
FT2	0.01	0.16	0.44
FGT	0.03	0.19	0.49
FST	0.01	0.23	0.71

(c) LM tests of non-linearity

Variable	i_{t-1}	y_{t-1}	$E_t\pi_t$	E_ty_t	$E_t\pi_{t+4}$	Str_t	VXO_t
FT2	0	0	0.04	0	0	0.01	0.12
FGT	0	0	0.01	0	0	0.02	0.04
FST	0	0	0.13	0	0	0.01	0.14

(d) LM tests of parameter constancy

Null:	All coefficients constant			All except intercept constant		
	LM_1	LM_2	LM_3	LM_1	LM_2	LM_3
FT2	0	0	0	0	0	0
FGT	0	0	0	0	0	0
FST	0	0	0	0	0	0

Table 3: **LSTAR specification tests**

Transition Variable:	$E_t\pi_{t+4}$			E_ty_t		
Tests	F-stat	df	p-value	F-stat	df	p-value
$H_3 : \beta_3 = 0$	0.56	(3,85)	0.64	4.95	(3,85)	0
$H_2 : \beta_2 = 0 \vert \beta_3 = 0$	6.13	(6,86)	0	5.97	(6,86)	0
$H_1 : \beta_1 = 0 \vert \beta_2 = \beta_3 = 0$	10.12	(3,91)	0	11.94	(3,91)	0

If p-value to H_2 smallest, select LSTAR2. For all others select LSTAR1.

2.5.2 LSTAR Taylor rules

Table 4 gives the estimates of the LSTAR1 version of the Taylor rule. A standard grid search was used to get the initial values for γ_1 and c_1 in the NLS estimation of (7).[17] From this procedure we find that the output gap threshold c_1 has an estimated value of -1.66% and $\gamma_1$is around 86. In the *Normal* regime ($E_t y_t > -1.66\%$) we are in a relatively stable period and observe that the coefficients for inflation and the output gap are positive and significant ($B_2 = 1.81$ and $B_3 = 0.72$ respectively). So in the *Normal* regime the Fed is simply following a standard Taylor rule. However, in the *Distressed* regime ($E_t y_t < -1.66\%$) the Fed's estimated response is unsatisfactory under a Taylor rule as it does not respond to the output gap (α_3 actually has a negative sign) and inflation (α_2 is not significant at the 5% level). Using expost data, Kazanas et al. (2011) also find the Fed not reacting to the output gap and inflation during recessions. Further we have a highly significant negative intercept term ($\alpha_0 = -4.0$) that indicates a drastic drop during this regime.[18]

Figure 5 identifies the particular economic periods during the Greenspan era that correspond to the *Distressed* regime in the LSTAR1 model. The regime seems to match well with the key economic shocks of the period such as the Savings and Loans crisis, the early '90s recession and the 9/11 attacks along with the technology-sector fuelled stock market crash. Further in Figures 6 we look at how the Fed Funds rate responded in the LSTAR1 regimes and it becomes quite apparent that the Fed pursued an expansionary policy whenever it was in the Distressed Regime. So based on these LSTAR1 estimates we can easily determine that the Fed uses significant discretion when responding to economic shocks. Further this

[17]The grid search was run on the reduced form of (7) i.e $f_t = \varphi x_t G(.) + \omega x_t(1 - G(.))$ where $x_t = [1, f_{t-1}, y_t, \pi_{t+4}]$ for intervals $10 < \gamma_1 < 1000$ and $-2.5 < c_1 < 2.5$ (5000 steps). Long run responses with standard errors using the delta method.

[18]The estimated a_0 is much lower than the predicted intercept value of -1.2 for a Taylor rule with the inflation coefficent $\zeta_\pi = 1.62$ and the parameters $r^* = 2.85\%$ and $\pi^* = 2.5\%$.

Table 4: **LSTAR1 estimates**

	Constant	i_{t-1}	$E_t y_t$	$E_t \pi_{t+4}$	RMSE	AIC	SBC
Distressed Regime	-4.00***	0.74***	-0.28	2.62*	0.41	1.13	1.34
$(E_t y_t \leq c_1)$	(1.13)	(0.08)	(0.33)	(0.68)			
Normal Regime	0.77	0.65***	0.72***	1.81***			
$(E_t y_t > c_1)$	(0.46)	(0.05)	(0.11)	(0.20)			
	$\gamma_1 = 86$	$c_1 = -1.66$					

Standard errors robust to heteroskedasticty and serial correlation in parenthesis.
***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

discretion took place during the supposedly Rules-Based Era (1985-2003) and so casts doubt on Taylor's (2012) view that Fed pursued an ad hoc monetary policy only after 2003. Indeed Greenspan (2004) justifies this flexible approach:

> As a result, risk management often involves significant judgment as we evaluate the risks of different events and the probability that our actions will alter those risks....prescriptions of formal rules can, in fact, serve as helpful adjuncts to policy. But at crucial points, like those in our recent policy history (the stock market crash of 1987, the crisis of 1997-1998 and the events that followed September 2001), simple rules will be inadequate as either descriptions or prescriptions for policy....no simple rule could possibly describe the policy action to be taken in every contingency.

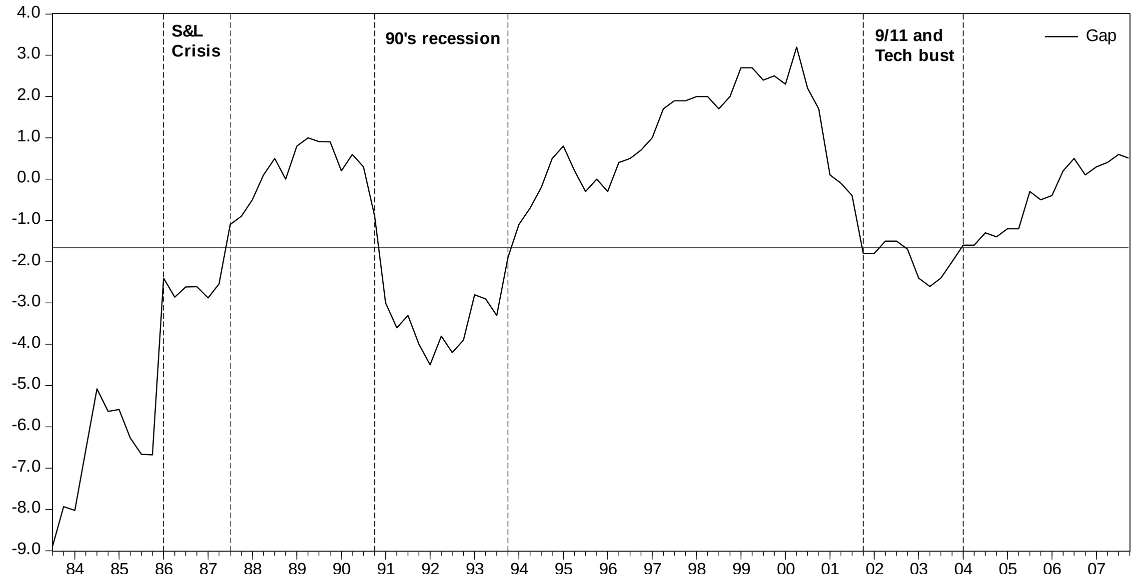

Figure 5: Regimes of the LSTAR1 model during the 'Great Moderation'. Output gap estimates are from the Greenbook data. Economy in a Distressed regime if $E_t y_t < -1.6\%$.

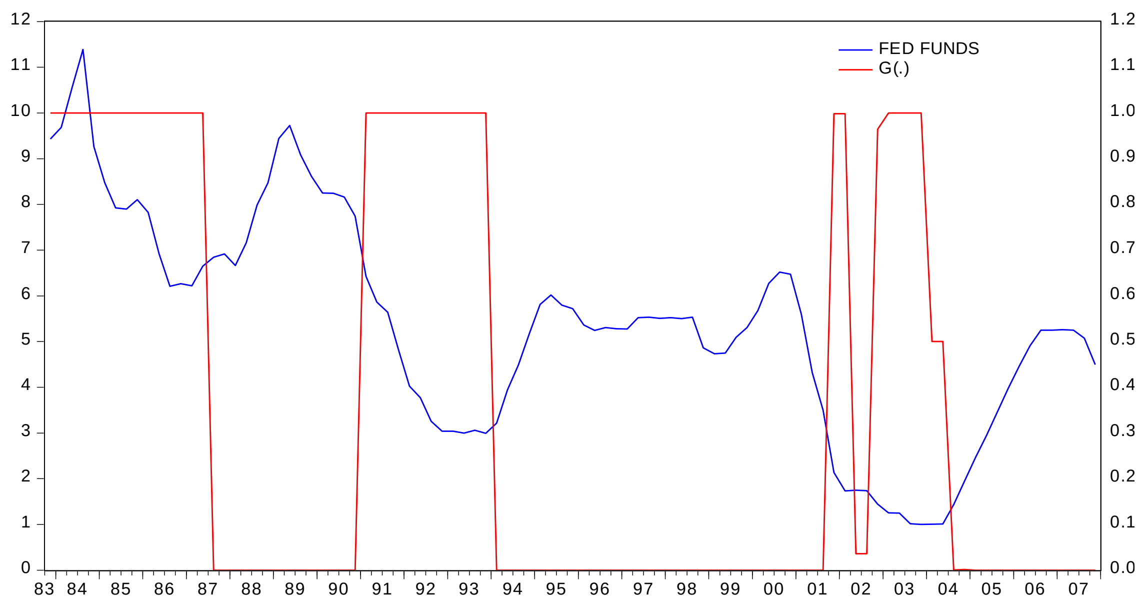

Figure 6: Fed's response in the Distressed and Normal regimes of the LSTAR1 model. Normal if $G(.) = 0$ and Distressed if $G(.) = 1$. LHS axis for Feds Fund. RHS axis for $G(.)$

We next turn to the LSTAR2 model in (8) with the estimated responses given in Table 5. Initial values for the two threshold values c_2 and c_3 along with γ_2 are again obtained using a grid search procedure and indicate the Fed's lower and upper bounds for inflation at $\pi_L = 1.6\%$ and $\pi_U = 3.1\%$.[19] Notably this $(1.6, 3.1)$ interval encompasses the Fed's implicit point target of 2.5% that was found earlier with our linear Taylor rules. A target range for inflation is often preferable as it gives the Fed greater latitude in conducting monetary policy. Further, π_U being closer to 2.5% suggests that the Fed has been more sensitive to inflation that is above target levels. Figure 7 also shows that the Fed was quite successful in keeping actual inflation (*expost* series) within this desired range during the Great Moderation.

When $E_t\pi_{t+4}$ is outside this target interval ($E_t\pi_{t+4} < 1.6$ or $E_t\pi_{t+4} > 3.1$) the Fed has a strong and significant response to inflation with $B_3 = 2.49$. On the other hand, the response to the output gap is insignificant. Orphanides and Van Norden (2005) show a weak relationship between future inflation and the real-time estimates of the current output gap. The Fed seems cognizant of this fact with $E_t y_t$ and $E_t\pi_{t+4}$ having a negative correlation of -0.39 for the full sample and so it is not surprising to see a lack of response to the output gap in this regime.

Figure 8 looks at the response on the Fed Funds rate in each of the two LSTAR2 regimes and we can see the Fed in this *Outer* regime is motivated primarily by inflation and raised interest rates to counter inflationary pressures in the economy. The Outer regime in 2002-2004 is a result of inflation being below the Fed's lower bound and so the decrease in interest rates in this period is also consistent with a strong response to inflation. In the Inner regime, $E_t\pi_{t+4}$ is within the Fed's target interval and we see that the response to the output gap increases ($\alpha_3 = 0.78$) and is highly significant. However, the Fed's response to inflation drops

[19]The grid search was conducted on the reduced form of (8) with intervals $50 < \gamma_2 < 500$ and $1.0 < c_2 < 2.0$ and $2.5 < c_3 < 3.5$.

($\alpha_2 = 1.94$) and is no longer significant at the 5% level. Thus we can determine that the Fed in the *Inner* regime is not actively trying to get inflation toward a point target, matching previous findings in Martin and Milas (2010) and Lamarche and Koustasy (2012).

Table 5: **LSTAR2 estimates**

	$Constant$	i_{t-1}	$E_t y_t$	$E_t \pi_{t+4}$	RMSE	AIC	SBC
Inner Regime	0.60	0.73***	0.78***	1.94*	0.43	1.22	1.43
($c_2 \leq E_t\pi_t \leq c_3$)	(0.25)	(0.05)	(0.15)	(1.05)			
Outer Regime	-1.70	0.75***	0.01	2.49***			
($E_t\pi_t < c_2$ *or* $> c_3$)	(0.62)	(0.08)	(0.13)	(0.24)			
	$\gamma_2 = 26$	$c_2 = 1.6$	$c_3 = 3.1$				

Standard errors robust to heteroskedasticty and serial correlation in parenthesis.
***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

Figure 7: Actual inflation and the Fed's target interval during the Great Moderation. Actual inflation uses expost data. Lower bound: $E_t\pi_{t+4} = 1.6\%$ and upper bound: $E_t\pi_{t+4} = 3.1\%$.

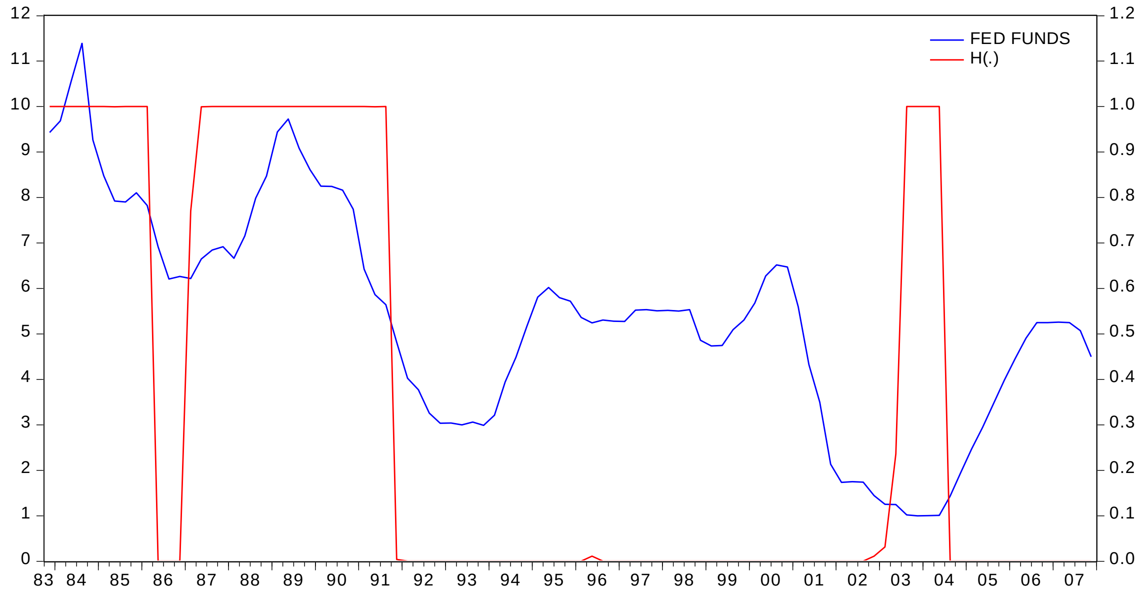

Figure 8: Fed's response in the Outer and Inner regimes of the LSTAR2 model. Inner regime if $H(.) = 0$ and Outer regime if $H(.) = 0$. LHS axis for Feds Fund rate. RHS axis for $H(.)$

In terms of goodness of fit, both the LSTAR models have lower AIC and SBC values than their linear counterparts. The Relative Root Mean Square Errors (Rel. RMSE) for the two LSTAR models with respect to *FT2* come out to 0.86 and 0.90 respectively, further indicating that the in-sample fit of the two LSTAR models is superior to the best fit linear Taylor rule in Table 1.[20]

Table 6 gives the p-values for the LM tests of no remaining nonlinearity. The first of the LM type tests is the standard test of no additive nonlinearity developed by Eitrheim and Teräsvirta (1996). However, these LM tests check only for additive nonlinearity and so may miss out on multiple regimes. So we need to test both the LSTAR models against an MRSTAR alternative using the test developed in Dijk and Franses (1999). The results from these LM tests indicate that we can safely reject the null that the LSTAR specification is sufficient for this instance.

[20]See Brüggemann and Riedel (2011) for details on the Relative RMSE calculations.

Table 6: **Test for remaining nonlinearity in STAR models**

	Second Threshold	LM test	*p-values*	MR test	*p-values*
LSTAR1 Model	$E_t\pi_{t+4}$	0.89	(0.50)	1.79	(0.04)
LSTAR2 Model	$E_t y_t$	2.25	(0.01)	2.70	(0.00)

LM test is against additive STAR model and MR test is against the MRSTAR model.

2.5.3 MRSTAR Taylor rule

Before proceeding with the estimation of the MRSTAR model, we give an economic interpretation for the regimes in this model. Figure 9 shows that there will be four distinct regimes based on the value of the two threshold functions $G(.)$ and $H(.)$. The *Normal & Outer* regime occurs when we have stable output ($E_t y_t > c_1$) and inflation that is outside the Fed's preferred interval ($E_t\pi_{t+4} < c_2$ *or* $> c_3$). In the *Distressed & Outer* regime we have distressed levels of output ($E_t y_t < c_1$) and inflation that is still outside the interval. In the *Distressed & Inner* regime output is expected to be distressed and inflation still lies inside the interval. Finally in the *Normal & Inner* regime the economy is expected to have stable output levels and inflation will be inside the desired interval ($c_2 < E_t\pi_{t+4} < c_3$).

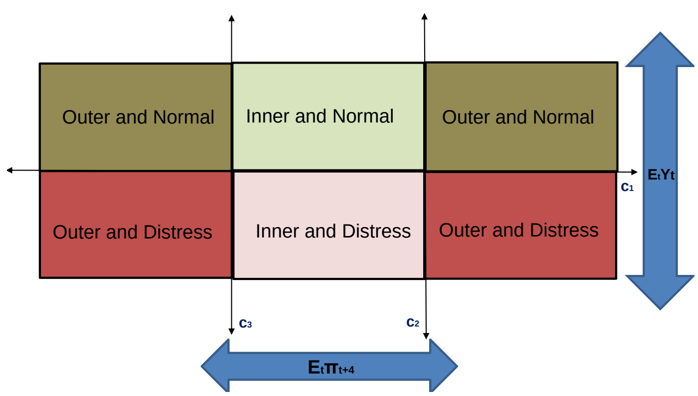

Figure 9: Potential regimes in the MRSTAR model with both inflation and output gap acting as thresholds.

We again employ a grid search to obtain the initial values of the thresholds in the MRSTAR model.[21] The threshold estimates for the output gap comes out to $c_1 = 0.47\%$ while the respective thresholds for inflation are $c_2 = 1.45\%$, $c_3 = 3.10\%$. A concern in estimating multiple regimes is that these models may be over-parameterized. However a preliminary sample split, based on these thresholds, found that each regime of the MRSTAR Taylor rule had at least 15-20 unique observations which mitigates some of these concerns. The inflation thresholds in particular are close to the ones found for the LSTAR2 specification. We also find a clear difference in the estimates of the smoothing parameters. In particular $\gamma_1 = 120$, which is the speed of transition between the *Normal* regime and the *Distressed* regime, is much higher than $\gamma_2 = 10$ which governs the transition between the *Inner* regime and the *Outer* regime. So this suggests that the Fed is more willing to move from one policy regime to another in response to shocks to output than inflation ($\gamma_1 > \gamma_2$).

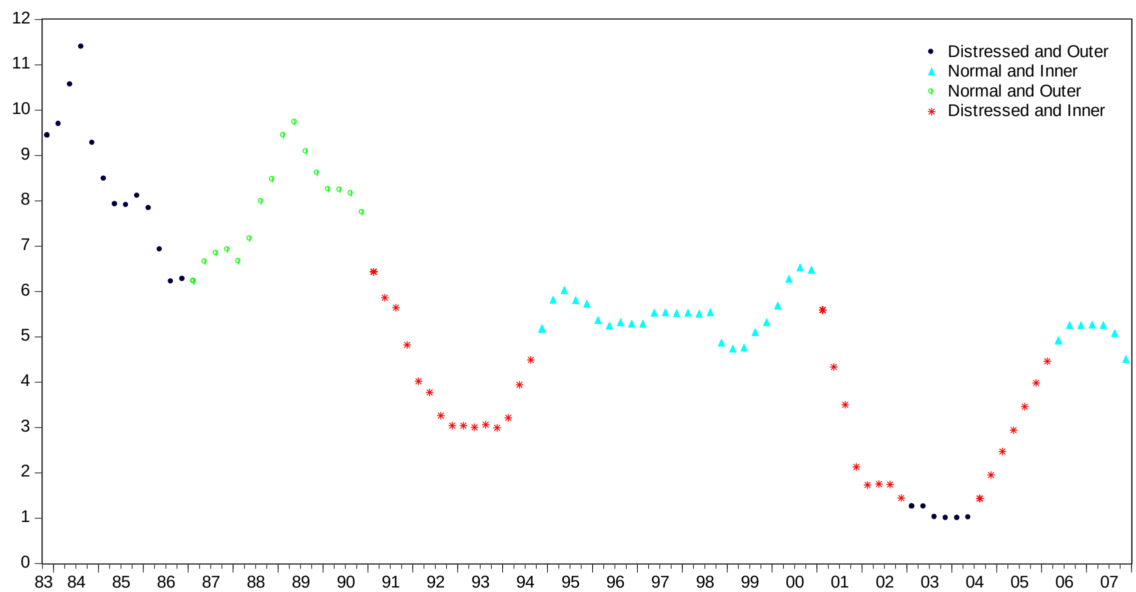

Figure 10: Using the estimated MRSTAR regimes to characterize the Fed's response during the Great Moderation.

[21] In order to speed convergence and reduce the computation burden, we reduced the range for the thresholds in our five-dimensional grid search. See Appendix B for more details.

Table 7: **Corellation in the MSTAR regimes**

(a) **Normal & Inner Regime**

	$E_t y_t$	$E_t \pi_{t+4}$
i_t	-0.06	0.03

(b) **Normal & Outer Regime**

	$E_t y_t$	$E_t \pi_{t+4}$
i_t	0.64	0.93

(c) **Distressed & Inner Regime**

	$E_t y_t$	$E_t \pi_{t+4}$
i_t	0.95	0.75

(d) **Distressed & Outer Regime**

	$E_t y_t$	$E_t \pi_{t+4}$
i_t	0.83	0.79

In Figure 10 we use the threshold estimates to classify each sample observation into one of the four MRSTAR regimes. We thus get a succinct overview of the different economic circumstances the Fed faced during the Great Moderation as well as see the rationale for some of its policy decisions. In Table 7 we also look at the correlation between the Fed Funds rate and the Fed's forecasts of inflation and the output gap in the MRSTAR regimes. We observe that in the *Normal & Inner* regime there is very low correlation between these variables and so supports the view of the Fed being passive in this regime. On the other hand, we see high correlations between the policy rate and output gap forecasts in both of the *Distressed* regimes. Finally inflation forecasts have a strong correlation with the policy rate only in the *Normal & Outer* regime. These correlations thus give us some insight on what the Fed's main focus was in each of these regimes.

We next use the values of these thresholds and smoothing parameters from the grid search to estimate (9) by NLS and get the Fed's response in the MRSTAR regimes. Table 10 reports these estimates. In the *Normal & Outer* regime, we see that the Fed has a very strong and significant response to inflation with $\alpha_2 = 2.17$. However the Fed's response to the output gap is not significant even at the 10% level. This suggests that the Fed in this regime is concerned only with inflation and tries to reduce inflationary pressures by raising policy rates. The lack of response to the output gap in this regime provides support for Cukierman and Gerlach (2003) and thier belief that policy makers are not interested in intentionally increasing positive output gaps.

When we move to the *Distressed & Outer* regime we see that the Fed takes a significant departure from the Taylor rule. First the Fed has a very small and insignificant response to the output gap ($B_3 = -0.06$). More critically the Fed's response to inflation, while significant, drops to $B_2 = 0.80$ and so is in clear conflict with the *Taylor Principle* (ζ_π needs to be greater than 1). A low response to inflation along with a significant negative intercept term indicates that the Fed has an expansionary monetary stance in this particular regime. The response in this regime is consistent with Alcidi et al. (2011) findings that the Fed's judgment during crisis periods played a substantial role in observed deviations from the Taylor rule.

In the *Distressed & Inner* regime we continue to find the Fed having a relatively low response to inflation with $q_2 = 0.86$ and insignificant at the 5% level. On the other hand the response to the output gap increases to $q_3 = 0.25$ and is also highly significant. So it seems that the Fed has a stronger response to the output gap once inflation gets within the desired target range. Moreover, the weak response to inflation in both of the MRSTAR's *Distressed* regimes shows that during economic contractions the Fed is less concerned with inflation and instead places a greater emphasis on output stabilization. Indeed the only time the Fed has strong response to inflation in the MRSTAR model is when output is at the target level.

Lastly in the *Normal & Inner* regime we find an interesting response function in that the Fed does not respond to either inflation or the output gap (both coefficients are insignificant at the 10% level). Thus Fed policy is very passive in this regime which seems intuitive given that both inflation and output levels are close to policy objectives and match the random walk response seen in Lamarche and Koustasy (2012). However, the difference is that our regime also accounts for the output being at a relatively normal level and so gives a much stronger economic rationale for a passive policy response.

Table 8: **MRSTAR estimates**

	$Constant$	i_{t-1}	$E_t y_t$	$E_t \pi_{t+4}$
Normal & Outer	-0.05	0.81*	1.43	2.17***
	(0.20)	(1.41)	(0.84)	(0.56)
Distressed & Outer	-0.67***	0.66***	-0.06	0.80***
	(0.21)	(0.11)	(0.03)	(0.24)
Distressed & Inner	-0.31	0.68***	0.25***	0.86**
	(0.69)	(0.06)	(0.05)	(0.36)
Normal & Inner	-0.93	0.96***	0.21	0.45
	(1.27)	(0.11)	(0.16)	(0.31)
	$\gamma_1 = 120$	$\gamma_2 = 10$		
	$c_1 = 0.47$	$c_2 = 1.45$	$c_3 = 3.10$	

Standard errors robust to heteroskedasticty and serial correlation in parenthesis.
***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

We next make sure that the estimated MRSTAR model does not have any significant misspecification issues. Table 9 provides the results for these tests (see Appendix C for the derivation of these misspecification tests). Auto-correlation become less of an issue for the MRSTAR model while the LM tests provide evidence of coefficient stability. We also use the parsimonious Ramsey RESET alternative to check for any remaining nonlinearity. The RESET makes use of the linear combination of the powers of fitted values and so can be used to detect issues of omitted variables and incorrect functional forms. P-values from the RESET provide no evidence of any misspecification in our MRSTAR model. These tests indicate that the MRSTAR model is a good fit for the Fed's response and should be preferred over the LSTAR models.

We now use our MRSTAR estimates in Table 8 to shed more light on the Fed's loss function

Table 9: **P-values of misspecification tests for MRSTAR model**

(a) LM test of no autocorrelation

Lags	4	6	8
	0.02	0.03	0.10

(b) LM test of no ARCH

Lags	4	6	8
	0.01	0.71	0.57

(c) LM test of parameter constancy

Null:	All parameters constant		
	LM_1	LM_2	LM_3
	0.00	0.29	0.06

(d) RESET Nonlinearity test

Null:	$\lambda_i = 0$		
	$i = 1$	$i = 1, 2$	$i = 1, 2, 3$
	0.65	0.23	0.39

RESET test uses the predicted values from the nonlinear model.

during this era.[22] As in Assenmacher-Wesche (2006), we assume that the Fed is responding optimally in each of the MRSTAR regimes. The distinct responses then seem to indicate a loss function that is highly state-dependent, as suggested by Bec et al. (2002). Accordingly we modify (2) and propose the following loss function:

$$L(\pi_t, y_t) = \left\{(\pi_t - \pi^*)^2\right\} I_{[\pi_t < c_2; > c_3]} + \left\{r_y y_t^2\right\} I_{[y_t < c_1]} + r_i(i_t - i_{t-1})^2 \tag{10}$$

where $I[.]$ is the indicator function and r_y, r_i are the relative weights. This loss function has the additional feature that it penalizes the Fed only when inflation is outside some desired interval (so capturing opportunistic monetary policy). Further having observed that the Fed does not respond to positive output gaps once inflation is controlled for, losses from output are only allowed to occur if the economy is in a distressed state. The Fed's responses indicate a strong preference for interest-rate smoothing across the MRSTAR regimes, and so is incorporated in the loss function as well. Overall this loss function looks as a promising candidate capable of generating the Fed's observed responses in the MRSTAR regimes.

We test the robustness of our findings by using the real-time Philladelphia Fed economic data set, as described in Section 2.3, in the estimation. In order to facilitate estimation with

[22]Note that there is no way to employ structural models with real-time data(Dennis, 2006).

this data source and keep our empirical strategy intact we let $k = 0$, $h = 0$ in (6) and so is no longer forward-looking. Taylor (1999) has argued that since they all incorporate the same information, forecast-based rules are as forward-looking as those that use lagged values.

Table 10 provides the MRSTAR estimates for this particular data source. The estimated threshold for the output gap is now slightly higher as $c_1 = 0.69\%$ while the range for inflation is much broader with $c_2 = 1.64\%$ and $c_3 = 3.7\%$. In the *Normal & Outer* regime we see the Fed following a standard Taylor rule with a significant response to the output gap ($a_2 = 0.21$) and inflation ($\alpha_3 = 2.26$). In the *Distressed & Outer* regime the Fed has a weak response to inflation ($B_3 = 0.80$) and so is not in compliance with the *Taylor Principle*. In the *Distressed & Inner* regime the Fed only responds to the output gap as the response to inflation is not significant at the 5% level. Finally the Fed does not respond in the *Normal & Inner* regime.

Table 10: **MRSTAR estimates with alternate real-time data**

	$Constant$	i_{t-1}	$E_t y_t$	$E_t \pi_{t+4}$
Normal & Outer	-0.40**	0.86***	0.21***	2.26**
	(0.16)	(0.05)	(0.06)	(0.10)
Distressed & Outer	-0.62***	1.08***	-0.02	0.80***
	(0.37)	(0.11)	(0.89)	(0.24)
Distressed & Inner	4.04	0.77***	0.51***	0.89*
	(1.96)	(0.03)	(0.05)	(0.47)
Normal & Inner	-0.39	0.97***	0.11	0.19*
	(0.32)	(0.03)	(0.09)	(0.11)
	$\gamma_1 = 213$	$\gamma_2 = 33$		
	$c_1 = 0.69$	$c_2 = 1.39$	$c_3 = 3.86$	

Standard errors robust to heteroskedasticty and serial correlation in parenthesis.
***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

2.5.4 Extension to the Financial Crisis

In order to examine the impact of financial crisis, we first extend the Greenbook data set with the Fed's forecasts of output gap and inflation for the crisis years of 2008 and 2009. It seems reasonable in this analysis to focus on these two years given that the policy rate reached the zero-bound at the end of 2009. We then use the latest Greenbook forecasts along with the pre-crisis MRSTAR Taylor rule, using the estimates in Table 8, to predict the interest rates in this period and compare them across the different regimes. Having models with multiple regimes allow us to conduct this sort of counterfactual analysis and we can get an interesting overview of how policy would have reacted in alternate regimes to the same economic conditions.

Figure 11 looks at the interest rates that would have been implied in 2008 and 2009 if the Fed had followed the baseline linear Taylor rule *(FT2)* versus if the Fed had followed the MRSTAR Taylor rule. We can see from Figure 11 that the actual policy rates during this period are much closer to the MRSTAR response in the *Distressed & Inner* regime than the rates implied by the linear Taylor rule.[23] Thus the nonlinear MRSTAR Taylor rule does a better job in predicting the Fed's actions during the early stages of the crisis. Further we see that the MRSTAR model also predicts negative policy rates at the end of 2009. This is in line with the challenges policy makers faced with the zero-lower bound during this period and the subsequent development of unconventional monetary policies to combat the severity of the recent recession.

We further conduct a counterfactual exercise to determine what the policy rates would have been if the Fed's response was consistent with the other regimes of the MRSTAR model. As

[23]The Fed's forecasts of the state of the economy in these two years corresponded to the *Distressed & Inner* regime of the MRSTAR model.

shown in Figure 12, if the Fed had responded as if it was in the *Inner & Normal* regime then the Fed Funds would not have seen much change during the financial crisis. Alternatively if the Fed had responded as if it was in the *Outer & Normal* regime then it's focus would have remained on inflation and thus in the initial stages of the crisis it would have been unwilling to reduce policy rates by a large amount. Once inflation subsided in 2009, we see a slight drop in the predicted rates and so indicates that the Fed in this regime would only allow the rates to fall if inflation was under control. Overall our analysis points out that the Fed under these alternative regimes would have been less accomodative during the financial crisis and as a result we could have had an even more severe economic downturn in this period.

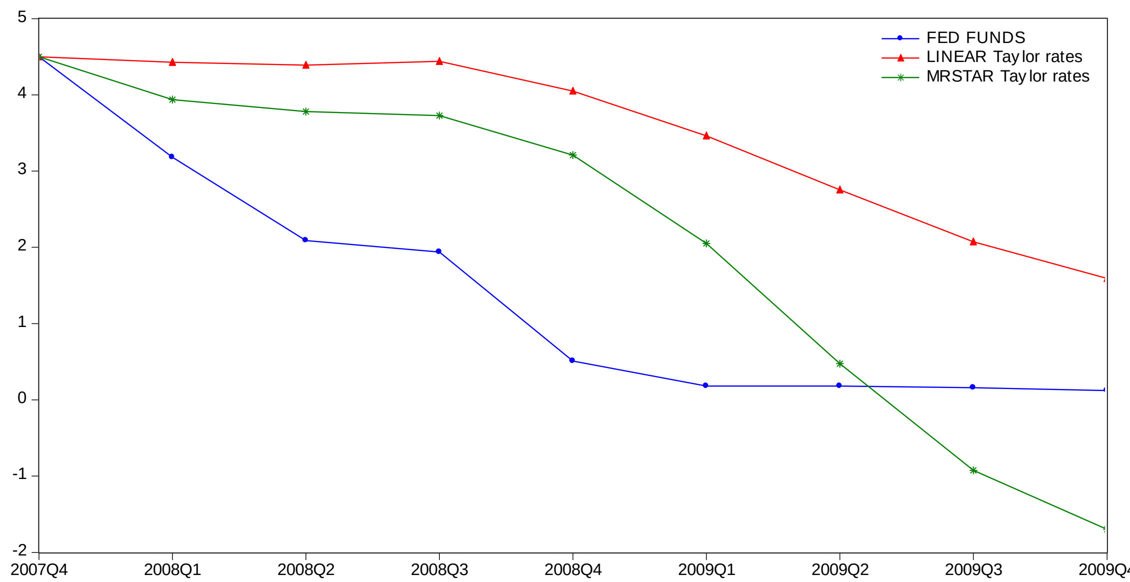

Figure 11: Implied Fed policy rates during the Financial Crisis using estimates of the Linear Taylor rule and the MRSTAR response in the Distressed and Inner regime.

2.6 Conclusion

In the last three decades monetary policy has undergone a remarkable turnaround with central banks now seen as a major source of economic stability. The Fed has been especially

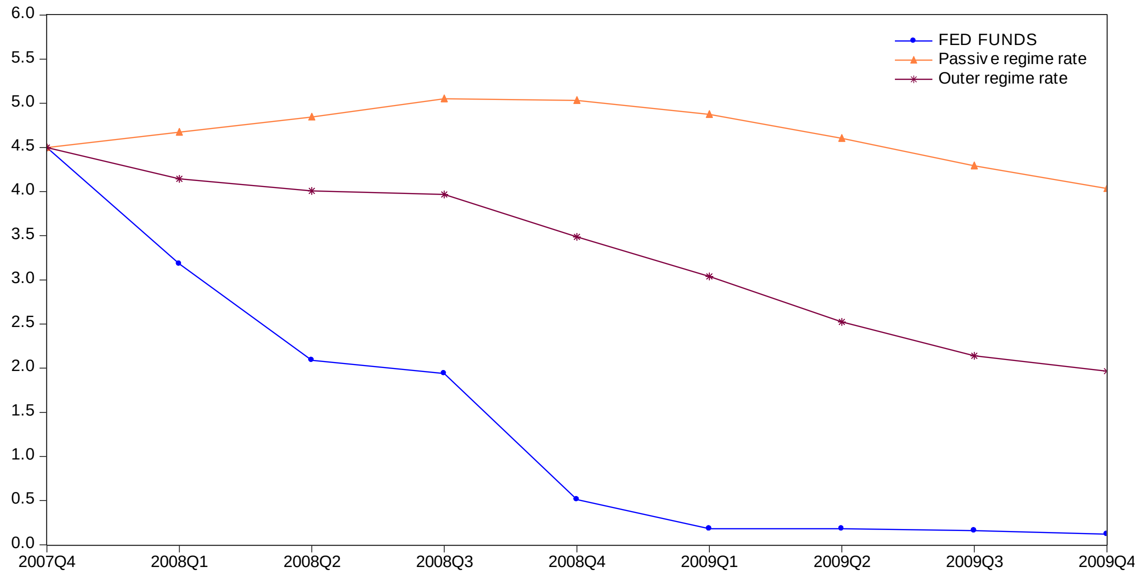

Figure 12: Counterfactual Fed policy rates during the Financial Crisis. Passive corresponds to the Inner and Normal regime while Outer corresponds to the Outer and Normal regime of the MRSTAR model

credited for successfully implementing a "fine-tuning" approach to monetary policy that has kept inflation and the output gap close to their targets (Blinder and Reis, 2005). In this paper we have tried to get a better understanding of the Fed's policy response by using a broad nonlinear framework with real-time data, two elements that are often been missing from this literature.

Our results show that there is significant nonlinearity in the Fed's response reflecting asymmetric preferences toward both the output gap and inflation. By using a flexible MRSTAR model we are able to estimate the Fed's response in four distinct economic regimes and see a much stronger response to a negative output gap and inflation that is outside the Fed's target interval. Notably the responses in some of these regimes do not fall under a Taylor rule, suggesting that while the Fed prefers a systematic approach to monetary policy it also employs considerable discretion in trying to achieve key policy objectives. We are also able to propose a state-dependent loss function that can generate such nonlinearities in the Fed's response function. Finally the MRSTAR model is also able to provide insight on the Fed's response during the financial crisis and we see that the sharp drop in policy rates is consistent with one of regimes of the model.

An interesting opportuniy for future research is to examine the fit of the flexible MRSTAR model to other central banks. We also do not need to restrict the thresholds to only the traditional Taylor rule variables. So depending on the central bank's policy mandate, factors such as financial stress or exchange rate considerations (Lubik and Schorfheide, 2007) can be easily incorporated in the MRSTAR framework. It would certainly be quite notable if inflation targeting central banks such as the Bank of Enagland and the European Central Bank also reduce their emphasis on inflation during crisis periods. For, as we have shown, there remains a great deal of validity for Mishkin (2007) view that successful monetary policy will always have an element of art to go along with the science.

2.7 Appendix

2.7.1 Unit root tests

We test for stationarity by first using the Augmented Dickey Fuller (ADF) test as given in Said and Dickey (1984). Table 11 shows that the null of a unit root is rejected for all of our main variables except the Greenbook forecasts of inflation (GB Inflation) and the real-time Philladelphia Fed inflation series (RT Inflation). However it is known that the ADF test has low power against relevant alternatives which can lead to misleading analysis. Thus we supplement this test with the Ng-Perron test (Ng and Perron, 2001) which has better power and less size distortions. For robustness we have also included the KPSS test (Kwiatkowski et al., 1992) which tests for the null that the series is actually stationary. Overall these tests indicate that we can treat our variables as stationary in the empirical analysis.

Table 11: Unit Root Tests

	ADF test		Ng-Perron test		KPSS test	
	H_0 : Series has unit root		H_0 : Series has unit root		H_0 : Series is stationary	
	t	CV= -2.89	MZ_α	CV= -8.10	Z^*	CV= 0.46
Fed Funds Rate	-3.28	No	-17.67	No	0.38	Yes
GB Inflation	-1.47	Yes	-9.04	No	0.35	Yes
GB Output Gap	-3.79	No	-8.40	No	0.36	Yes
RT Inflation	-2.26	Yes	-4.19	Yes	0.32	Yes
RT Output Gap	-3.16	No	-24.30	No	0.33	Yes

Lag length selected based on the modified AIC criteria. The KPSS Test is computed with the Bartlett kernel and the Andrews automatic bandwidth selection. Critical values given at the 5 percent level for all tests.

2.7.2 Grid Search Procedure

We now detail the steps that we took to get the initial starting values for the smoothing and threshold parameters $(\gamma_1, c_1, \gamma_2, c_2, c_3)$ in equation (5). Reminder that $c_1$is the threshold for the output gap forecast while c_2 and c_3 are the lower and upper thresholds for the inflation forecast.

We started the grid search with the following intervals:$-1.5 < c_1 < 1.5$, $1.25 < c_2 < 1.75$ and $2.5 < c_1 < 3.5$. These initial intervals for the thresholds are selected based on the estimates of the LSTAR specifications. The smoothing parameters $\gamma_1$and γ_2 had an upper bound of 1000 in these searches. Our first task is to narrow the range of c_1 interval in the grid search. We attempt this by keeping the rest of the intervals the same and only changing the intervals for c_1. The step size in these searches is 500 for c_1, 100 for c_2 and c_3 and 50 for the smoothing parameters. Based on the R-square criteria, we find strong support that $c_1$lies in the interval (0.45, 0.50).

We next try to narrow the intervals of c_2 and c_3 by restricting c_1 be in the (0.45, 0.50). interval only. The step size in these grid searches is 50 for c_1 and 500 for c_2 and c_3. Based on the R-square criteria, c_2 was found to be in the interval (1.35, 1.45) while c_3 was found to be in the (2.95, 3.05) interval. We then run a final grid search on these narrow intervals and were able to determine the following initial values $\gamma_1 = 120$, $c_1 = 0.47$, $\gamma_2 = 10$, $c_2 = 1.45$, $c_3 = 3.10$. These values are then used to estimate (10) by NLS.

2.7.3 MRSTAR Misspecification tests

Teravirta (1998) gives a detailed derivation of the misspecification test for the basic STAR model. Starting with the general case:

$$y_t = M(x_t;\psi) + u_t \tag{11}$$

where M is twice continuously differentiable with respect to the parameters and $u_t \sim iid\, N(0,\sigma^2)$. So when (11) is the LSTAR1 case we have:

$$M(x_t;\psi) = \phi_1' x_t + \phi_2' x_t G(s_t;\gamma,c) \tag{12}$$

where $G(.)$ is given as the logistic function with $k=1$ and $\psi = (\phi_1', \phi_2', \gamma, c)$. An important component of these LM tests is that we have to calculate the partial derivatives of the log-likelihood function with respect to the parameters of the model ψ and so will be needing

$$\frac{\partial M(x_t;\psi)}{\partial \psi} = \left(\frac{\partial M}{\partial \phi_1'}, \frac{\partial M}{\partial \phi_2'}, \frac{\partial M}{\partial \gamma}, \frac{\partial M}{\partial c}\right)' = \left(x_t', x_t' G(.), g_\gamma(s_t), g_c(s_t)\right)' \tag{13}$$

Further it can be shown that

$$g_\gamma(s_t) = G(.)\left\{1 - G(.)\right\}(s_t - c)\phi_2' x_t \tag{14}$$

$$g_c(s_t) = \gamma G(.)\left\{1 - G(.)\right\}\phi_2' x_t \tag{15}$$

We next employ a similar strategy for when (11) is given by the MRSTAR specification. Note that the model in (9) can be reparametrized as:

$$M(.) = \phi_1' x_t + \phi_2' x_t G_1(s_{1t};\gamma_1,c_1) + \phi_3' x_t G_2(s_{2t};\gamma_2,c_2,c_3) + \phi_4' x_t G_1 G_2 \tag{16}$$

So now we have $\psi = (\phi_1^{'}, \phi_2^{'}, \phi_3^{'}, \phi_4^{'}, \gamma_1, c_1, \gamma_2, c_2, c_3)$ and need the following partials

$$\frac{\partial M(x_t;\psi)}{\partial \psi} = \left(x_t^{'}, x_t^{'}G_1(.), x_t^{'}G_2(.), x_t^{'}G_1(.)G_2(.), g_{\gamma_1}, g_{c_1}, g_{\gamma_2}, g_{c_2}, g_{c_3}\right)^{'}.$$

Solving for these partials for (16), we get

$$\begin{aligned} g_{\gamma_1} &= \phi_2^{'}x_t\frac{\partial G_1(.)}{\partial \gamma_1} + \phi_4^{'}x_tG_2(.)\frac{\partial G_1(.)}{\partial \gamma_1} \\ &= G_1(.)\left\{1 - G_1(.)\right\}(s_{1t} - c_1)\phi_2^{'}x_t + G_1(.)G_2(.)\left\{1 - G_1(.)\right\}(s_{1t} - c_1)\phi_4^{'}x_t \end{aligned}$$

$$\begin{aligned} g_{c_1} &= \phi_2^{'}x_t\frac{\partial G_1(.)}{\partial c_1} + \phi_4^{'}x_tG_2(.)\frac{\partial G_1(.)}{\partial c_1} \\ &= \gamma_1 G_1(.)\left\{1 - G_1(.)\right\}\phi_2^{'}x_t + \gamma_1 G_1(.)G_2(.)\left\{1 - G_1(.)\right\}\phi_4^{'}x_t \end{aligned}$$

$$\begin{aligned} g_{\gamma_2} &= \phi_3^{'}x_t\frac{\partial G_2(.)}{\partial \gamma_2} + \phi_4^{'}x_tG_1(.)\frac{\partial G_2(.)}{\partial \gamma_2} \\ &= G_2\left\{1 - G_2\right\}(s_{2t} - c_2)(s_{2t} - c_3)\phi_3^{'}x_t + G_1G_2\left\{1 - G_2\right\}(s_{2t} - c_2)(s_{2t} - c_3)\phi_4^{'}x_t \end{aligned}$$

$$\begin{aligned} g_{c_2} &= \phi_3^{'}x_t\frac{\partial G_2(.)}{\partial c_2} + \phi_4^{'}x_tG_1(.)\frac{\partial G_2(.)}{\partial c_2} \\ &= \gamma_2 G_2(.)\left\{1 - G_2(.)\right\}(s_{2t} - c_3)\phi_3^{'}x_t + \gamma_2 G_1(.)G_2(.)\left\{1 - G_2(.)\right\}(s_{2t} - c_3)\phi_4^{'}x_t \end{aligned}$$

$$\begin{aligned} g_{c_3} &= \phi_3^{'}x_t\frac{\partial G_2(.)}{\partial c_3} + \phi_4^{'}x_tG_1(.)\frac{\partial G_2(.)}{\partial c_3} \\ &= \gamma_2 G_2(.)\left\{1 - G_2(.)\right\}(s_{2t} - c_2)\phi_3^{'}x_t + \gamma_2 G_1(.)G_2(.)\left\{1 - G_2(.)\right\}(s_{2t} - c_2)\phi_4^{'}x_t \end{aligned}$$

With these partials in $\frac{\partial M(x_t;\psi)}{\partial \psi}$ we are now able to use the rest of Teräsvirta (1994) LM test methodology for our MRSTAR model.

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3 Chapter 2

Globalization and Inflation: A Threshold Investigation

Abstract

We use a threshold methodology to investigate the importance of non-linear effects in the analysis of the inflation globalization hypothesis. Accounting for potential non-linearities in the Phillips Curve, we show that trade openness is not rejected as a threshold variable for the effects of domestic and foreign slack on inflation in many advanced economies, and we find a switch of the output gap slopes from one regime to the other that is consistent with the key predictions of the inflation globalization hypothesis. For some countries the threshold Phillips Curve model also leads to improvements in out-of-sample forecast over the linear Phillips models, especially at longer horizons. Contrary to most of the previous literature which ignores such non-linearities, our new approach provides some interesting empirical evidence supportive of the effect globalization has on a country's inflation dynamics.

3.1 Introduction

The view that highly interconnected markets will allow global factors to replace domestic determinants of inflation, also known as the inflation globalization hypothesis, has recieved a substantial level of attention, in part due to its significant policy implications. One of the main predictions of the inflation globalization hypothesis is that the role of the foreign output gap in the determination of domestic inflation will increase at the expense of the domestic output gap as the country's economic integration increases. This prediction typically has been examined in the context of the Phillips Curve model; however, due to mixed empirical findings, there is little consensus on the importance of the foreign output gap, and thus globalization, in a country's inflation process. Borio and Filardo (2007) show that including a measure of foreign slack in a reduced Phillips Curve framework is appropriate for every country in their sample. However, their findings have come under considerable skepticism with Ihrig et al. (2010) illustrating that these results do not hold when a more traditional approach to inflation expectations is employed in the empirical analysis. More recently, Bianchi and Civelli (2015) show the importance of accounting for time variations in the investigation of inflation dynamics, and they find that in a time-varying VAR framework the impact of the foreign output gap on domestic inflation is positively related to trade openness.

In this paper, we continue this line of inquiry but depart from the standard framework by explicitly allowing a country's level of trade openness, used as a proxy for the degree of globalization of a country, to have a non-linear role in the Phillips Curve.[1] Our goal is to show the existence and empirical relevance of a threshold effect of trade openness on the relation between inflation and the domestic and foreign output gaps, such that inflation responds to

[1] Similarly, trade openness has been found to exert non-linear effects on growth rates. See, for example, in this respect Cuaresma and Doppelhofer (2007), El Khoury and Savvides (2006) and Papageorgiou (2002).

external factors only after a country achieves a certain level of openness.[2] A number of economic factors can motivate this type of non-linear behavior. For instance, Sbordone (2007) shows that one of the ways globalization can affect the structural determinants of inflation is by reducing the market power of domestic sellers through increased competition; however, it may be the case that domestic companies start to pay attention to foreign competitors only after they have captured a significant market share. This non-linearity should not be omitted from the analysis of the inflation globalization hypothesis, and exploring it in a systematic manner could lead to greater insight on the relationship between inflation and openness and assist policy makers to better deal with some of the challenges of globalization.

Applying Hansen's (1997; 2000) threshold methodology, we are able to examine the non-linear effects of openness on inflation at the individual-country level for a sample of 16 OECD economies. Considering possible threshold effects of trade openness in a Phillips Curve framework is a simple way to assess directly the effects of globalization on inflation. We follow a two-stage empirical strategy to document some interesting new evidence in favor of the use of the threshold approach in evaluating the inflation globalization hypothesis. In the first stage of the analysis, we identify the countries for which the non-linearity is statistically meaningful. It is quite possible that some countries just do not reach a level of openness to experience a shift in their inflation dynamics. In such instances the threshold methodology does not give us any additional insight in the relationship between inflation and globalization. In the second stage of the analysis, we examine the countries that do pass the test for a significant threshold and determine whether the switch of the output gap slopes from one regime to the other is consistent with the key predictions of the inflation globalization hypothesis.

[2]Most of the empirical evidence against the inflation globalization hypothesis ignores potential non-linearities that might affect inflation dynamics.

The results show that for most of our sample countries the level of trade openness is a statistically significant threshold variable for the analysis of the effects of domestic and foreign slack on inflation. In the first stage, we find that openness is not a meaningful threshold in our preferred specification of the Phillips Curve for only four countries; these are typically the economies with the lowest degrees of openness, like the U.S. or Japan. In the second stage, we find a broad support of the inflation globalization hypothesis from all the remaining countries after accounting for the non-linear relationship. For half the countries the estimated output gap responses in the two regimes are consistent with the theoretical predictions of the hypothesis. For the other half we find a switch of the coefficient of either foreign or domestic gap that is in line with the hypothesis. Finally, we also find interesting variation in the estimated thresholds across countries, which reflects the structural differences embedded in the level of openness across economies.

Our baseline non-linear model is deliberately simple. For robustness we conduct a number of checks for this choice of specification. In particular, we find no significant impact from allowing inflation to have a downward trend; we also find that our main results are robust to the use of different definitions of inflation and to the inclusion of oil prices, real exchange rates, and import prices as additional controls. Finally, we assess the out-of-sample forecast performance of our model in comparison to its linear alternatives, finding an improvement in the forecast fit for some of the countries, especially at longer horizons.

The remainder of the paper is organized as follows. Section 3.2 discusses the related literature. Sections 3.3 and 3.4 respectively describe our data and the linear Phillips Curve results for our sample of countries. In Section 3.4.2, we move to the threshold analysis and examine the role of openness in a country's inflation dynamics. Section 3.4.3 illustrates the robustness checks to the baseline specification of the model. Finally, in Section 3.5 we examine some of the policy implications of our results and conclude.

3.2 Related Literature

The traditional approach in modeling inflation dynamics has been to focus on country-specific factors, such as domestic output, while leaving a limited role for external factors that were usually captured in the form of supply shocks. However, the increased level of globalization that has taken place through higher levels of trade, financial integration, and movement across factor markets might have changed the very nature of the inflation process. It may now very well be the case that a country's prices are more influenced by events happening in the global rather than the domestic markets.

A theoretical justification to focus on external factors in the inflation process is also provided by Gali and Monacelli (2005), who extend the micro-founded New Keynesian Phillips Curve to the open-economy case. Their key insight is that inflation depends on the weighted average of the domestic and foreign output gaps, where the weights represent some preference for home goods. The inclusion of the foreign output gap in the Phillips Curve shows that along with the direct effects of trade, such as import prices or real exchange rates, there is also a need for some measure of excess global demand, since low demand in one country could be countered by high demand in another.[3] Similarly, Engel (2013) investigates how the Phillips Curve for the consumer price inflation in a country is affected by openness. He compares a model that assumes producer currency pricing with one under local currency pricing, within a theoretical framework in which domestic inflation is directly affected by the global economy through the foreign output gap and imported-goods inflation. He shows that the exchange rate affects inflation not only in the producer currency pricing model due to perfect pass-through, but also in the local currency pricing model through the movements of the term of trade due to a wealth redistribution across countries. We rely on this strand of the theoretical

[3] In the extreme, as pointed out by Borio and Filardo (2007), this implies that excess demand should be aggregated at the product rather than the country level.

literature to justify our empirical approach and to gain a better understanding of the overall relationship between globalization and inflation.

A number of studies have used the open-economy Phillips Curve framework to investigate the inflation globalization hypothesis. The empirical evidence, however, is still quite ambiguous as seen by the contrasting findings of Borio and Filardo (2007) and Ihrig et al. (2010). Gamber and Hung (2001) show that globalization increased the sensitivity of U.S. inflation to foreign economic conditions in the '90s. For a group of advanced economies, the IMF (2006) and Pain et al. (2006) also find a reduction in sensitivity of inflation to domestic capacity constraints due to increased globalization, although in the latter case this is primarily captured through the import channel. On the other hand, Calza (2009) finds that globalization in the form of global output gaps has little success in explaining domestic inflation for the Euro area as a whole. Using a structural model for the G7 countries, Milani (2010) also determines that global output impacts domestic inflation indirectly, and thus it should not be included in the Phillips Curve specification. Finally, in a New Keynesian framework, Sbordone (2007) provides an analytical justification for the diminishing sensitivity of inflation to domestic output fluctuations in response to increased globalization and reduced market power of domestic producers.

3.3 Data Description

The data for our empirical analysis comes from Bianchi and Civelli (2015) and consists of quarterly observations from 1985 to 2006 for a panel of 16 OECD countries: Australia, Austria, Canada, Denmark, France, Germany, Ireland, Italy, Japan, Korea, Mexico, Netherlands, Spain, Switzerland, UK, and the U.S. For each country, the dataset for the baseline specification of the non-linear model includes domestic inflation measured by the Consumer

Price Index, the domestic and foreign output gaps, a measure of trade openness, and the effective real exchange rate.

The foreign output gap and the real exchange rate are respectively constructed as trade-weighted averages of the domestic output gaps and pairwise exchange rates of the country's trade partners. The weights are obtained starting from the series of the pairwise import and export flows among a set of about 50 countries which, besides the 16 countries in our sample, includes all the OECD countries, the major Asian economies, and some other emerging countries. The weights are computed following the approach used by the Federal Reserve Board in the construction of its effective real exchange rate. The weights are meant to measure the relative importance of an international partner for a country. This is achieved accounting both for the direct relations between two countries, given by the relative share of imports and exports from one country to the other, and for the so-called third-party relations, which are used to take into account the indirect effects due to international competition among countries.[4,5]

The domestic output gap of a country is constructed as the percentage deviation from the HP-filtered real GDP series taken as a proxy for the potential GDP. The source for the real GDP is the OECD National Account Statistics or the IMF. For each of the 16 countries in our non-linear analysis the domestic output gaps of all the other countries are then weighted to form the trade-based measure of the foreign gap. The foreign output gap is then specific to each country. The same procedure applies to the construction of the country-specific

[4]The formulas for the imports, w^m, exports, w^x, and third-party weights, w^3, are:

$$w^m_{i,j,t} = \frac{M_{i,j,t}}{\sum_{j=1}^{N_t} M_{i,j,t}}; \quad w^x_{i,j,t} = \frac{EX_{i,j,t}}{\sum_{j=1}^{N_t} EX_{i,j,t}}; \quad w^3_{i,j,t} = \sum_{k\neq j,\neq i}^{N_t} w^x_{i,k,t} \frac{w^m_{k,j,t}}{1 - w^m_{k,i,t}}$$

where $M_{i,j}$ is import from country j to country i, $EX_{i,j}$ export from country i to country j.

[5]The trade flows data come from the IMF-DOT database. See Bianchi and Civelli (2015) for more details and the list of countries used in the trade-weights sample.

real exchange rates. The pairwise nominal exchange rates, generally obtained from Global Insight, are deflated by the CPI of the respective country, and aggregated using the same trade-based weights.

Trade openness is defined as the ratio to GDP of the sum of imports and exports of a country. Following Borio and Filardo (2007) and Bianchi and Civelli (2015), the inflation rate is computed as the log-difference of the domestic CPI index relative to the same quarter of the previous year. The CPI values usually come from the IMF or OECD Main Economic Indicators (MEI) datasets, with base year set to 2000. Finally, for the robustness exercises we obtain data for core inflation using CPI (excluding all food and energy prices) from the OECD MEI while the import price deflator and global oil prices are from the OECD Economic Outlook dataset.

Table 1 sorts these countries based on their average level of openness. We see that there is significant variation, ranging from relatively closed countries such as the U.S. and Japan with levels of openness close to 20% of GDP to more open economies such as the Netherlands and Ireland with levels of openness close to 100% of GDP. Given these strong differences it would not be surprising if openness affected these countries asymmetrically.

In our analysis, we focus only on observations from 1985 onward to account for the structural break in inflation that was seen for most advanced economies in the early ′80s (Rapach and Wohar, 2005). Since this decrease in inflation rates was a result of more aggressive central bank actions, it would be inappropriate to link it solely with increased globalization (Calza, 2009). Thus we adopt a conservative approach and avoid the earlier periods, even though these were also years that experienced relatively steady growth in international trade. Finally, ending the sample in 2006 allows us to compare our results directly with earlier literature, while also avoiding the impact of the global financial crisis and the subsequent decline in international trade (Wynne and Kersting, 2009).

Table 1: OECD data (1985-2006)

Country	Code	Open	Inf
US	US	0.170	3.01
Japan	JPN	0.176	0.68
Australia	AUS	0.296	3.86
Spain	SPN	0.333	4.42
Italy	ITA	0.353	3.95
France	FRA	0.388	2.23
UK	UK	0.400	3.63
Mexico	MEX	0.401	23.0
Germany	GER	0.472	1.83
Denmark	DEN	0.528	2.57
Korea	KOR	0.564	4.41
Canada	CAN	0.565	2.68
Switzerland	SWZ	0.568	1.83
Austria	AUT	0.654	2.19
Netherlands	NET	0.903	2.05
Ireland	IRE	1.032	3.08

Quarterly averages, sorted by the country's average level of openness.

3.4 Phillips Curve Analysis

3.4.1 Linear Results

We begin with a linear Phillips Curve model that lays the groundwork for the non-linear analysis in Section 3.4.2. To analyze the effect of globalization on domestic inflation, we employ an open-economy version of the Phillips Curve so that the foreign output gap is added to the baseline empirical specification and obtain a set of standard results for our 16 OECD countries. The linear model can be expressed in general form as

$$\pi_t = \alpha + \sum_{k=1}^{L} \rho_k \pi_{t-k} + \beta Y_t^d + \gamma Y_t^f + \varepsilon_t \tag{1}$$

where inflation, π_t, is related to its L lagged realizations and the contemporaneous domestic and foreign output gaps, Y_t^d and Y_t^f respectively. While this purely backward-looking specification may lack some of the structural interpretation of an explicit forward-looking New Keynesian Phillips Curve (Gali and Monacelli, 2005), it still provides a suitable reduced-form analysis of inflation dynamics. Furthermore, there is also some strong evidence that the backward-looking model is a better empirical fit (Rudd and Whelan, 2007) and more structurally stable (Estrella and Fuhrer, 2003) than pure forward-looking models. Using this same specification, Ihrig et al. (2010) show that the foreign output gap is not statistically significant for any country in their sample.[6]

Table 4 illustrates the estimates of a specification of model (1) in which we include one lagged value of inflation and the average of the subsequent four lags for the 16 countries in our sample. Our results are broadly consistent with those in Ihrig et al. (2010) (see their Table 1), with most of the countries showing very little role for the foreign output gap. As in Ihrig et al. (2010), the foreign output gap coefficient is often negative and nearly always insignificant. The only exception is Ireland, which, being a very open economy, sees an impact from the foreign output gap on its inflation significant at 10%. This is an interesting result because Ireland is the most open country in our analysis, based on the trade index adopted here, with a level of openness about two times the average. Table 4 shows that the domestic output gap is also insignificant for most of the countries, a recurrent finding in open-economy Phillips Curves.[7] Finally, the LM tests for serial autocorrelation and hetroskedasticity along with the RESET tests indicate that equation (1) is properly specified.[8]

[6]Ihrig et al. (2010) also employ a variety of controls for supply shocks such as energy and food prices as well as tax dummies, but these did not impact their main results.

[7]Indeed, the domestic output gap gains significance when we exclude the foreign output gap from the estimation.

[8]We also estimate (1) using a Seemingly Unrelated Regression framework as in IMF (2006), allowing for common shocks. The results reported in Table A1 are quite similar.

3.4.2 Threshold Results

Based just on the linear estimates in Table 4 one may conclude that, save for Ireland, the inflation process in all other countries has not been greatly influenced by globalization, and that policy makers should continue to focus on the domestic determinants of inflation. However, as has been pointed out by Bianchi and Civelli (2015), a simple linear Phillips Curve model is insufficient to assess satisfactorily the inflation globalization hypothesis. The evolution of globalization needs to be explicitly embedded in the analysis, allowing for the possibility of both non-linearity and heterogeneity across countries and thus allowing us to gain a better understanding of this complex relation.

One simple and effective way to allow for non-linear effects of globalization on inflation is to modify the Phillips Curve model in (1) as a threshold model. The Threshold Phillips Curve is then given as

$$\pi_t = \alpha + \sum_{k=1}^{L} \rho_k \pi_{t-k} + \begin{cases} \beta_1 Y_t^d + \gamma_1 Y_t^f + \varepsilon_t & when\ Openness \leq \theta_0 \\ \beta_2 Y_t^d + \gamma_2 Y_t^f + \varepsilon_t & when\ Openness > \theta_0 \end{cases} \tag{2}$$

where trade openness acts as the threshold variable and is responsible for the switch in the relation between inflation and the output gaps from one regime to another.

Globalization can be measured over several dimensions besides trade openness; we choose to use trade openness mainly for two reasons. First, trade openness has often been used as a proxy for the degree of globalization of a country in empirical work, and it is especially relevant for our purposes since inflation in an open-economy Phillips Curve framework is directly affected by external factors through the trade channel. Second, as illustrated for instance by Engel (2013), in the theoretical open-economy models of the New Keynesian

Phillips Curve not only is domestic inflation is affected by the foreign output gap and movements in the exchange rates, but also the importance of these international factors increases as trade openness increases.

An important caveat to bear in mind about our approach is that trade might not fully capture the full complexity of the globalization process. Clearly, a limitation of our approach is that using trade openness as a threshold variable and trade-based weights for the construction of the relevant foreign output gap of a country might be not be exhaustive if other aspects of globalization are relevant for the dynamic of domestic prices. A couple of other channels come to mind. First, integration of financial markets plays an important role in wealth distribution across countries and, hence, international consumption sharing. So the degree of financial globalization could also affect domestic prices through the foreign output gap. Second, when domestic markets are contestable, the influence of higher globalization on domestic prices could manifest itself through the effects of a stronger threat of entry by new international competitors that lowers domestic prices; this channel, for example, would be independent of trade per se.

Based also on these theoretical insights, we opt for a deliberately simple specification for our baseline non-linear model in (2), in which we allow openness to influence only the slopes of the gaps, while the lagged inflation terms and the intercept are the same in each regime. In our analysis we found that possible non-linear effects on the autoregressive component were quite modest with most countries seeing relatively few gains in the in-sample fit from allowing the lag coefficients to switch as well.[9] Bick (2010) has also shown that regime

[9]To isolate possible non-linearities in the autoregressive component of the inflation equation, we also estimate a non-linear model that keeps the coefficients of the two output gaps fixed instead and find that for the overwhelming majority of our sample countries the Hansen(1997) F-test rejects a switch in the lag coefficients due to openness. This is not surprising as generally central bank policies are considered to be the main factor that drives shifts in the formation of inflation expectations (Bianchi, 2013).

intercepts can often play a significant role in threshold analysis and so in Section 3.4.3, we allow the constant term to change between regimes. In this stage of our analysis we also do not include other factors, such as import prices or the real exchange rate, as we prefer to solely focus on the predictions of the globalization hypothesis on the output gap coefficients. In Section 3.4.3 we see that the baseline results are generally robust when these factors are added as control variables. Overall, our preferred model in (2) is a very simple way to incorporate potential non-linearities that allow the foreign output gap to matter for the inflation process only for certain levels of openness.

We follow Hansen (1997, 2000) to both estimate and test our threshold models. A consistent estimate of θ_0 is one that minimizes the residual variance of (2) and can be found by a grid search over all the possible values of the threshold variable. For a given θ_0, the rest of the model becomes linear in the parameters and can be then estimated by OLS. θ_0 is also a nuisance parameter in standard F or LM tests that check for the significance of the threshold model by testing the null hypothesis $H_0 : \beta_1 = \beta_2, \gamma_1 = \gamma_2$. Thus, as in Hansen (1997), we apply a bootstrap method to approximate the distribution of the test statistics under the null, and then use it to obtain the corresponding bootstrapped p-values for these tests.

Our empirical strategy will proceeds in two stages. First, we analyze the thresholds to identify the countries for which the non-linearity in the relation is actually statistically meaningful. We formally test for the significance of the threshold model, and we relate the results to the level of openness of the countries. Clearly, the threshold methodology will not give us any additional insight for the relationship between inflation and globalization for the countries that do not pass the test.[10] Second, we further examine the countries for which the threshold model is not rejected to determine whether the switch of the slopes

[10]Note that a nonrejection of the H_0 in the F-test implies that a linear analysis of the inflation dynamics is appropriate.

Table 3: Hansen Test for Threshold Effect

	Aus	Aut	Can	Den	Fra	Ger	Ire	Ita	Jpn	Kor	Mex	Net	Spn	Swz	UK	USA
F-test	1.83	3.81	2.62	6.38	1.13	2.91	7.15	3.47	2.77	1.94	6.53	2.51	3.73	4.37	5.31	2.00
p-value	.13	.00	.03	.00	.44	.02	.00	.01	.16	.09	.00	.03	.01	.00	.00	.12

F-test is the value of the maximum F-statistic for the null of no-threshold effect with the corresponding bootstrapped p-values as in Hansen (1997, 2000).

from one regime to the other is consistent with the predictions of the inflation globalization hypothesis.

In the first stage of the analysis, we focus on the estimated thresholds; the results of the F-test for the significance of the threshold model are reported in Table 3. We find a quite large support for using a non-linear approach to examine the inflation globalization relation for the countries we study. The F-test and corresponding bootstrapped p-values indicate that openness is indeed a statistically significant threshold variable for all countries in the sample except for Australia, France, Japan, and the U.S. Table 1 shows that Australia, Japan, and the U.S. are the three countries that display the lowest average levels of openness in our sample, while France has the sixth lowest. This evidence suggests that low degrees of openness might not be sufficient even to trigger non-linear effects in Phillips Curve model.[11] Thus we can classify these four countries as having no globalization effect on inflation.

Table 5 illustrates the results of the estimated threshold models for the countries that see a significant threshold effect from openness. Like the linear model, the non-linear specification of (2) also uses one lagged value of inflation and the average of the subsequent four lags. Additionally, Figure 1 relates the estimated threshold of each country to its respective trade

[11] This interpretation may not apply to France, whose inflation is not affected by openness in a clear manner. While the domestic output gap loses significance in France's more open regime, we also observe quite high bootstrapped p-values. Using a state space framework, López-Villavicencio and Saglio (2014) have also shown that openness is not responsible for the decline in the response of France's inflation to its domestic output gap.

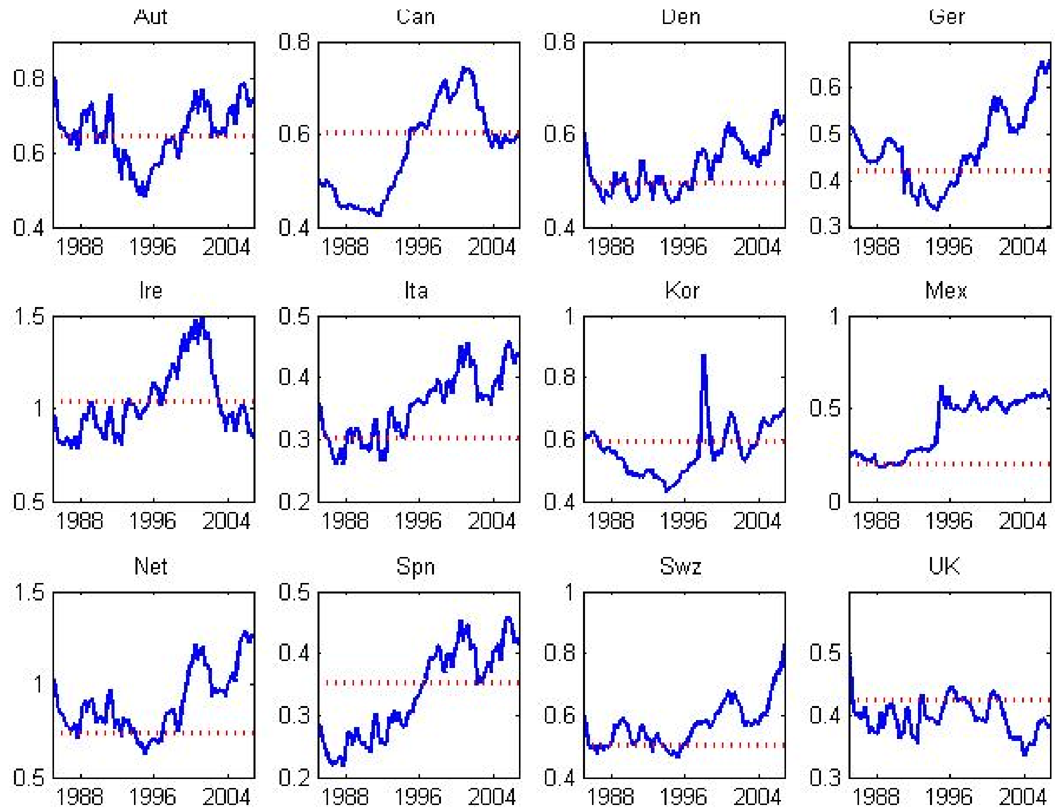

Figure 1: Evolution of trade openness and estimated thresholds.

openness index. The estimated thresholds show some level of heterogeneity with the median estimated threshold for openness at 49% and an inter-quartile range of 20%. This is not entirely unexpected as there are clear differences in the structural characteristics of these countries, especially in terms of the relative degree of integration in the global economy as has been documented in Table 1. Similarly, the magnitudes of the estimated effects of the two output gaps are characterized by good variability across countries, with more open economies having in general larger estimated thresholds as well as experiencing stronger effects of the foreign output gap. In this paper, our main purpose is documenting that countries experience similar threshold effects from openness in their domestic inflation dynamics rather than accounting for specific differences in the individual threshold estimates. Once the existence and importance of the non-linear effects are assessed, one could think of estimating an average effect of globalization on inflation in a panel framework, for instance, after imposing some restriction on the cross-sectional structure of the model.[12]

We turn next to the second stage of our empirical analysis. Table 3 showed that countries with low levels of openness did not experience a significant threshold effect on their inflation dynamics. While this is conceptually consistent with the non-linear role globalization can have in the inflation process, we still need to assess the main predictions of the inflation globalization hypothesis for all the remaining countries in our sample.

These predictions for the slopes of domestic and foreign output gaps across the two regimes can be stated as:

1. As we move to the more open regime, the responsiveness of inflation to the domestic output gap, β, is expected to decline, becoming less significant.

2. In the more open regime, the foreign output gap should replace the domestic output gap, indicating a more significant and larger estimate of γ.

Based on these estimated output gap coefficients, we can sort the countries in Table 5 into those displaying a full, a partial or no globalization effect. A full globalization effect is said to occur for a country in which, going from the less to the more open regime, the foreign and domestic output gap coefficients respectively turn from insignificant to significant and from significant to insignificant (at 10% level of confidence, at least). On the other hand, a partial effect is when we observe this change for only one of the two output gaps. Finally, we treat all the remaining cases as having no globalization effect on inflation, along with the countries for which the non-linear model is rejected. These classifications are quite

[12] In a companion paper, we exploit the cross-sectional dimension and the rich variation in openness across countries to generalize our result by estimating the threshold effects in a dynamic panel model.

conservative since the inflation globalization hypothesis also would be formally valid when both gaps are significant in the more open regime but the foreign gap is larger than the domestic gap. Thus, our findings in favor of the inflation globalization hypothesis can be viewed with even greater confidence.

Figure 2 helps us classify the countries for which a meaningful threshold is found. Solid bars correspond to the estimated domestic output gap coefficients, while the criss-cross patterns identify the coefficients for the foreign gap. The blue color is used to indicate switches in the parameter's magnitude and significance consistent with the globalization hypothesis predictions; gray indicates cases which are not in line with the globalization hypothesis. Given this information, it is easy to recognize that Austria, Canada, Denmark, Italy, and Mexico all experience a full globalization effect as they move toward the more open regime. The inflation dynamics for these nations are fully affected by an increase in globalization. In addition to them, Germany, Ireland, Korea, Netherlands, and Spain display a partial effect from openness that is reflected by a switch only in the foreign output gap. The estimates of the Y^f coefficients are large for all of them, and strongly significant for Germany and Ireland in particular; at the same time, the Y^d coefficient remains insignificant across regimes.[13] The UK and Switzerland, on the the other hand, display a partial globalization effect due to the domestic gap response, which loses significance in the more open regime. Overall, the observed non-linear relation between inflation and the output gaps is broadly consistent with the inflation globalization hypothesis for all the countries that pass the test of significance of openness as a threshold in the Phillips Curve model.

[13]It is important to note that Ireland's foreign output gap was significant in the linear case as well. Accounting for non-linearity, we find inflation has an even larger response to the external factors.

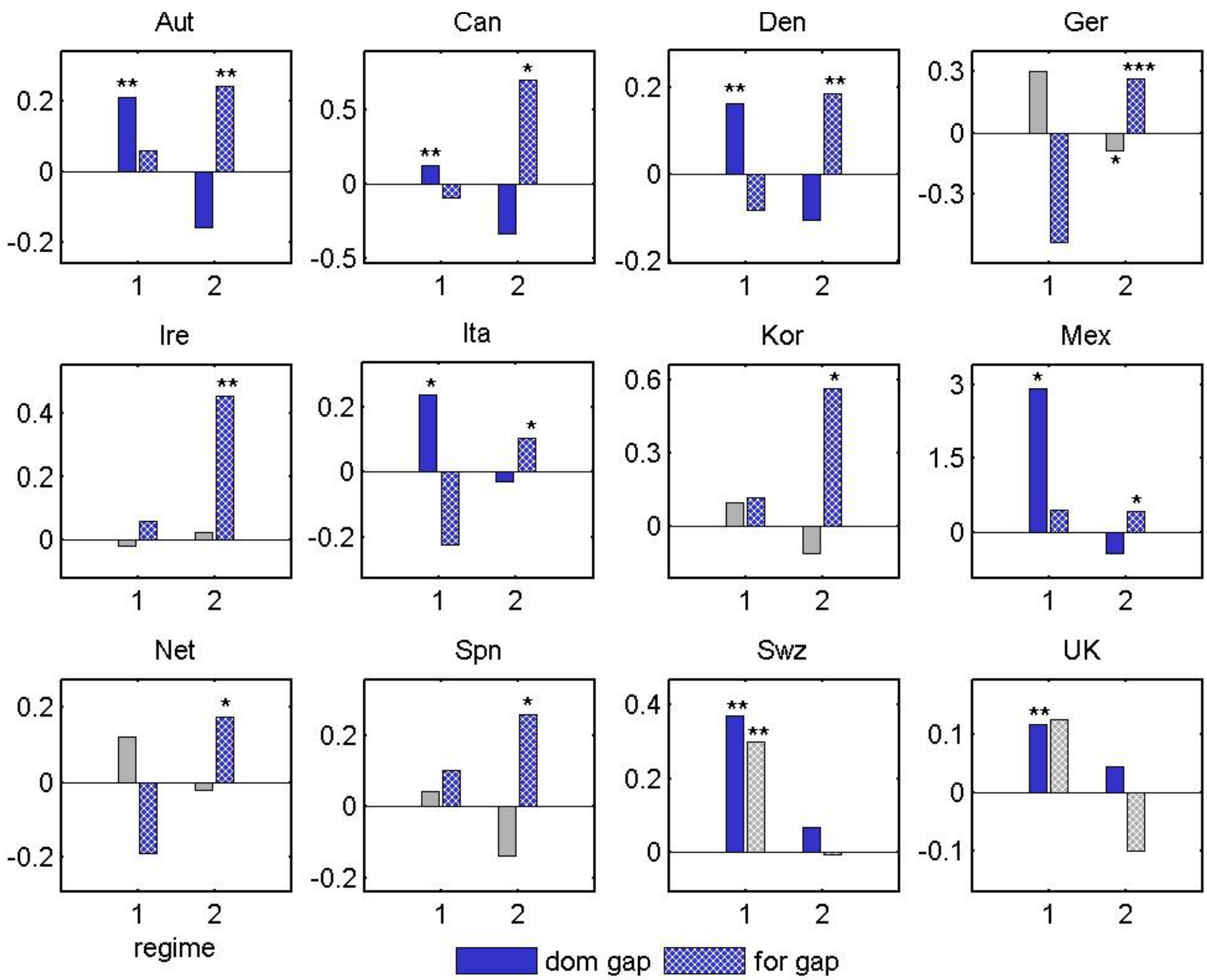

Figure 2: Blue (gray) bars indicate output gap responses to the regime switch consistent (not consistent) with the globalization hypothesis. */**/*** denotes significance at the 10/5/1 level.

Full globalization effect: Aut, Can, Den, Ita, and Mex. **Partial effect** (Y^d only): UK and Swz.

Partial effect (Y^f only**):** Ger, Ire, Kor, Net, and Spn;

Table 4: Linear Philips Curve

	Aus	Aut	Can	Den	Fra	Ger	Ire	Ita	Jpn	Kor	Mex	Net	Spn	Swz	UK	USA
Constant	0.37**	0.38***	0.36**	0.31**	0.27***	0.28**	0.53***	0.14*	0.07	0.68***	1.41	0.23**	0.32**	0.15**	0.48**	0.57***
	(0.18)	(0.13)	(0.18)	(0.13)	(0.10)	(0.15)	(0.16)	(0.10)	(0.06)	(0.23)	(0.91)	(0.09)	(0.14)	(0.08)	(0.22)	(0.18)
Lag Inf	1.02**	0.87***	0.88***	0.86***	0.88***	0.89***	0.95***	1.09***	0.83***	0.96***	1.19***	1.06***	0.85***	1.12***	0.99***	0.94***
	(0.06)	(0.09)	(0.05)	(0.10)	(0.08)	(0.07)	(0.05)	(0.04)	(0.07)	(0.04)	(0.08)	(0.07)	(0.08)	(0.05)	(0.05)	(0.06)
Avg Lag	-0.09	-0.04	-0.01	-0.01	-0.01	-0.04	-0.11**	-0.13**	0.05	-0.11	-0.25***	-0.16***	0.06	-0.19***	-0.12*	-0.12*
	(0.06)	(0.07)	(0.06)	(0.09)	(0.08)	(0.11)	(0.06)	(0.05)	(0.07)	(0.06)	(0.08)	(0.05)	(0.07)	(0.04)	(0.06)	(0.07)
Dom	0.09**	0.05	0.09	0.07	0.05	-0.03	-0.00	0.01	0.09	0.03	-0.15	-0.02	0.01	-0.03	0.11**	0.07
	(0.05)	(0.08)	(0.06)	(0.06)	(0.04)	(0.11)	(0.04)	(0.04)	(0.06)	(0.08)	(0.34)	(0.09)	(0.09)	(0.05)	(0.05)	(0.05)
For	-0.05	0.11	-0.04	-0.01	-0.03	0.13	0.13*	0.05	0.08	0.19	-0.06	0.12	0.15	0.09	0.04	0.01
	(0.13)	(0.07)	(0.12)	(0.06)	(0.06)	(0.09)	(0.07)	(0.07)	(0.08)	(0.14)	(0.48)	(0.11)	(0.11)	(0.07)	(0.11)	(0.08)
RMSE	0.81	0.38	0.63	0.43	0.38	0.63	0.51	0.35	0.52	1.00	4.73	0.39	0.56	0.42	0.62	0.47
Adj R^2	0.90	0.83	0.81	0.84	0.88	0.74	0.84	0.97	0.83	0.79	0.96	0.90	0.91	0.93	0.90	0.79
p-value†																
Serial	0.08	0.55	0.00	0.32	0.97	0.19	0.00	0.05	0.35	0.35	0.00	0.77	0.86	0.05	0.00	0.08
ARCH	0.71	0.08	0.37	0.00	0.67	0.48	0.81	0.07	0.32	0.74	0.00	0.19	0.00	0.30	0.75	0.46
RESET	0.90	0.01	0.35	0.58	0.11	0.90	0.15	0.50	0.55	0.58	0.24	0.13	0.66	0.00	0.62	0.51

Inflation based on the CPI. Lag Inf is π_{t-1} while Avg Inf is $\frac{1}{4}(\sum_{k=2}^{5} \pi_{t-k})$. HAC robust standard errors are in parenthesis.

†LM serial correlation test, ARCH test of conditional homoskedasticity and RESET is the Ramsey test

***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

Table 5: Threshold Phillips Curve

	Aut	Can	Den	Ger	Ire	Ita	Kor	Mex	Net	Spn	Swz	UK
Constant	0.489***	0.340*	0.313**	0.422***	0.686***	0.116*	0.574**	1.120*	0.227**	0.355*	0.117*	0.574***
	(0.13)	(0.17)	(0.12)	(0.12)	(0.15)	(0.07)	(0.22)	(0.60)	(0.10)	(0.17)	(0.07)	(0.17)
Lag Inf	0.873***	0.876***	0.810***	0.780***	0.866***	1.075***	0.933***	1.174***	1.023***	0.868***	1.067***	0.987***
	(0.08)	(0.08)	(0.13)	(0.08)	(0.06)	(0.06)	(0.06)	(0.08)	(0.06)	(0.08)	(0.06)	(0.05)
Avg Lag	-0.076	0.001	0.0476	-0.075	-0.080	-0.111**	-0.069	-0.212***	-0.132**	0.047	-0.132**	-0.129*
	(0.07)	(0.08)	(0.11)	(0.10)	(0.05)	(0.05)	(0.07)	(0.07)	(0.06)	(0.07)	(0.05)	(0.06)
Regime 1 (Open $\leq \theta_0$ ***)***												
Dom Gap	0.211***	0.120*	0.162**	0.302	-0.020	0.237*	0.101	2.933*	0.121	0.043	0.370**	0.117**
	(0.08)	(0.06)	(0.08)	(0.39)	(0.04)	(0.14)	(0.09)	(1.46)	(0.25)	(0.11)	(0.16)	(0.04)
For Gap	0.060	-0.092	-0.085	-0.540	0.061*	-0.223	0.121	0.457	-0.191	0.102	0.301*	0.126
	(0.08)	(0.13)	(0.09)	(0.42)	(0.06)	(0.22)	(0.13)	(1.39)	(0.19)	(0.15)	(0.15)	(0.09)
Regime 2 (Open $> \theta_0$)												
Dom Gap	-0.159	-0.331	-0.106	-0.09*	0.026	-0.031	-0.110	-0.432	-0.020	-0.136	0.067	0.045
	(0.11)	(0.19)	(0.07)	(0.05)	(0.09)	(0.04)	(0.16)	(0.28)	(0.07)	(0.22)	(0.05)	(0.24)
For Gap	0.242**	0.695*	0.184**	0.262***	0.456**	0.102*	0.565*	0.444*	0.175*	0.257*	-0.006	-0.099
	(0.10)	(0.39)	(0.08)	(0.09)	(0.17)	(0.06)	(0.34)	(0.25)	(0.09)	(0.14)	(0.06)	(0.22)
Threshold	0.648	0.604	0.497	0.423	1.041	0.303	0.595	0.305	0.734	0.354	0.502	0.425
Regime 1(%)	47	62	37	27	66	24	66	17	17	56	19	74
RMSE	0.37	0.61	0.40	0.62	0.48	0.34	0.99	4.44	0.38	0.54	0.41	0.59

Threshold are estimated so that each regime has at least 15% of observations in either Regime.

3.4.3 Robustness Checks

We next conduct a series of robustness exercises to check the validity of the main results based on our preferred specification of the non-linear model discussed in Section 3.4.2. Numerous interesting points are explored next, including the role of other possible competing international factors in the inflation dynamics to the econometric robustness of the specification of model (2).

Generally models of inflation that take into account a slowly evolving local mean perform better than purely stationary specifications (Faust and Wright, 2013). One way we account for this possibility is to have regime-specific intercepts in our threshold model and so allow for different means of inflation in the open and closed regimes. For most countries the open regime is associated with the later years of the sample, so a regime-specific intercept can account for the lower mean of inflation that has been observed in these OECD countries. As shown in Table A2, having regime-specific intercepts does not impact our threshold estimates and for most countries we see a similar switch in the output gap coefficients as in Table 5.

We further address the possibility of a persistent downward trend in the individual inflation series by demeaning the inflation series from a slow moving trend. In order to capture this trend component accurately, we employ an exponential smoothing method on each country's inflation series with a weighting scheme similar to Cogley (2002). Cogley (2002) shows that exponential smoothing filters out transient elements of CPI based inflation more effectively than other traditional detrending methods, while Rich and Steindel (2005) find that the exponentially smoothed series is able to track the underlying trend of inflation more closely than core inflation measures created by excluding food and energy prices from the CPI.

Table A3 in the Appendix shows the individual-country threshold estimates for inflation in deviation from its exponentially smoothed trend component. Again the estimates for most countries do not undergo much change from the baseline results in Table 5. We continue to see Austria, Denmark, Italy, and Mexico exhibiting a full globalization effect; Germany, Ireland and Netherlands exhibiting a partial effect due to the foreign gap only; and Korea, Spain, and the UK seeing an effect from the domestic output gap only. Only for Canada and Switzerland do we no longer observe any globalization effect when using the detrended inflation series. Thus our results in support of the inflation globalization are robust even after accounting for the downward trend of inflation in recent years.

We now consider specifications of the Phillips Curve in which we also allow traditional external factors, such as real exchange rate depreciation, import prices inflation, and oil prices, to have a role in determining domestic inflation. In our analysis we examine these external controls as separate cases since including them altogether in a single model can lead to issues of over-fitting and inaccurate inference, especially in the threshold case we are studying, where there might not be sufficient observations in each regime to get consistent estimates for a large number of parameters. This was also the strategy employed in Borio and Filardo (2007) to test for the impact of traditional controls on their open-economy Phillips Curve estimates.

From a theoretical perspective, Engel (2013) and Zaniboni (2008) have shown that besides the foreign output gap, the exchange rate depreciation (under producer currency pricing) or the term of trade (under local currency pricing) has a direct effect on inflation in the New Keynesian Phillips framework. Also empirically, Mihailov et al. (2011) have found with a GMM methodology that the relative change in the terms of trade is a more important factor in driving inflation than the current domestic output gap for a sample of OECD countries. We hence first consider the impact changes in the real exchange rate has on baseline threshold model given in (2).

Table A4 reports the results when the annual depreciation rate of the real exchange rate is used as an additional control variable (constructed as the log difference of the trade-weighted real exchange rate between one quarter and the same quarter of the previous year). As with the output gaps, we allow the impact of the real exchange rate to vary across the two regimes. All in all, these results are consistent with our earlier findings, with most countries continuing to have the same estimated thresholds and similar bootstrapped p-values from the F-test of threshold significance. Trade openness as a threshold variable for the inflation dynamics is still rejected for Australia, France, Japan, and the U.S. The remaining countries still have a statistically significant threshold effect, and display similar changes in their output gap slopes as before from the close to open regime. For most of the countries, the real exchange rate depreciation coefficient also does not switch in a consistent manner between the regimes. Two exceptions are Korea and Switzerland, for which the real exchange rate gains significance with the expected negative sign in the more open regime.[14] In the case of Switzerland, however, we no longer see a clear switch in the output gap slopes; for this country, the effect of trade openness on inflation seems to be better captured by the exchange rate channel than the foreign output gap.

We next turn to specifications that include oil and import prices as external controls in (2). Following Ihrig et al. (2010), we include both import prices inflation and oil price inflation as deviations from lagged core inflation so that an increase in these prices relative to domestic prices implies higher domestic inflation. Using the relative deviations of these supply shock variables is also consistent with the triangle model approach to capture inflation dynamics (Gordon, 2011). The estimates for the models with import prices illustrated by Tables

[14]The real exchange rate is defined so that an increase of it corresponds to an appreciation of the domestic currency and a loss of competitiveness of the domestic goods. A negative sign of its coefficient is expected in the Phillips Curve, and an increase in significance of this coefficient in the more open regime is consistent with the implications of the globalization hypothesis.

A5 of the Appendix. The results are generally robust to the use of oil prices as a supply shock, while the regime switch is less clear for some of the countries once import prices are included. In particular, we do not find a significant change in the output gap coefficients from the closed to open regime for Canada, Italy, and Switzerland. It is also important to stress that the effects of globalization related to the foreign output gap channel might in many ways overlap with those determined by import prices, since a positive foreign output gap would cause prices of foreign goods to increase and could be reflected in higher import prices for the domestic economy. So including import prices as a separate regressor can make it harder to empirically disentangle the effect of the foreign output gap from that of import prices, and can potentially mask a switch between the regimes, at least for some of the countries in our sample.

We now turn to the role of the energy and food components in the dynamics of domestic prices. It is important to understand whether the impact of globalization on inflation is a general phenomenon or more simply reflects the growing influence of global food and energy prices. We thus repeat the analysis of Section 3.4.2 using core inflation instead of CPI inflation in the threshold estimation. This substitution basically strips the more volatile food and energy prices from the CPI and allows us to focus on a narrower and more policy-oriented definition of inflation. For parsimony, we focus on the estimates without the external controls and just allow the output gaps to switch between regimes. In general these results with core inflation do not change much with the addition of the external controls.

Table A6 shows that the threshold Phillips Curve estimates are quite similar to those observed in Table 5, which is not surprising given that the two inflation series are highly correlated for most of the countries in our sample. Austria, Denmark, Mexico, and Korea exhibit a full globalization effect; Canada, Germany, Ireland, Netherlands, and Spain see a partial effect due to the foreign gap only; and Italy and the UK find a partial effect for the domestic output gap only. Notably, with core inflation both Australia and the U.S. also see a statistically significant non-linear effect from openness, with the domestic output gap coefficient losing significance in their more open regimes.

3.5 Conclusion

There are strong implications for the conduct of monetary policy if indeed it is the case that inflation is more influenced by global rather than domestic conditions. For one, a diminishing response to domestic factors implies an increase in the sacrifice ratio so that it becomes more costly to stabilize inflation through conventional policy actions (Calza, 2009). Alternatively, policy makers may feel that globalization adequately anchors inflationary tendencies through external competition and so are freer to concentrate on domestic output. Given these important policy consequences, it becomes imperative to identify the exact role globalization plays in the inflation process.

Our paper makes an interesting contribution to this debate by applying a threshold methodology to account for potential non-linear effects of trade openness on inflation dynamics. We find evidence that trade openness is not rejected as threshold variable for the Phillips Curve model for most of the countries in our sample, and this non-linear component must be explicitly modeled and included in the analysis of the inflation globalization hypothesis. We find that as countries reach a certain level of openness, their domestic inflation starts to respond to external influences as captured by the foreign output gap. At the same time, relatively closed economies that do not reach sufficient levels of openness, such as the U.S., do not exhibit such non-linearity in the relation between inflation and globalization. Accounting for non-linearities in the Phillips Curve reveals new evidence that contrary to the previous literature, which often ignores these effects, helps to corroborate the inflation globalization hypothesis. Our threshold approach is robust to many alternative specifications, and provides a suitable tool to inform the policy making process with respect to the influence of relevant external forces.

3.6 Additional Tables

Table A1: SUR Phillips Estimates

	Aus	Aut	Can	Den	Fra	Ger	Ire	Ita	Jpn	Kor	Mex	Net	Spn	Swz	UK	USA
Constant	0.50^{***}	0.52^{***}	0.50^{***}	0.31^{**}	0.29^{***}	0.29^{**}	0.62^{***}	0.25^{*}	0.09	0.60^{*}	1.79^{**}	0.18^{**}	0.52^{***}	0.18^{***}	0.52^{***}	0.85^{***}
	(0.16)	(0.09)	(0.13)	(0.12)	(0.07)	(0.12)	(0.14)	(0.07)	(0.06)	(0.24)	(0.77)	(0.08)	(0.14)	(0.07)	(0.15)	(0.14)
Lag Inf	0.94^{***}	0.82^{***}	0.85^{***}	0.85^{***}	0.86^{***}	0.84^{***}	0.99^{***}	1.10^{*}	0.82^{*}	0.97^{*}	1.20^{***}	1.09^{***}	0.78^{***}	1.04^{***}	0.94^{***}	0.85^{***}
	(0.06)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.08)	(0.06)	(0.04)	(0.06)	(0.07)	(0.04)	(0.05)	(0.05)
Avg Inf	-0.04	-0.05	-0.04	0.04	-0.01	0.01	-0.18^{***}	-0.17^{*}	0.04	-0.09	-0.28^{***}	-0.18^{***}	0.08	-0.14^{***}	-0.07	-0.12^{*}
	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.07)	(0.05)	(0.04)	(0.08)	(0.07)	(0.04)	(0.07)	(0.06)	(0.04)	(0.06)	(0.05)
Dom Gap	0.11^{**}	0.06	0.03	0.11^{**}	0.08	0.01	0.02	-0.03	0.10^{*}	0.02	-0.23	0.01	0.02	0.03	0.11^{***}	0.08^{*}
	(0.04)	(0.05)	(0.04)	(0.04)	(0.03)	(0.05)	(0.03)	(0.03)	(0.05)	(0.04)	(0.22)	(0.06)	(0.07)	(0.04)	(0.04)	(0.04)
For Gap	-0.03	0.11^{*}	0.03	-0.03	0.01	0.10	0.06	0.09	0.07	0.23	0.03	0.07	0.14	0.04	0.05	0.04
	(0.11)	(0.05)	(0.08)	(0.05)	(0.06)	(0.08)	(0.06)	(0.06)	(0.06)	(0.13)	(0.48)	(0.08)	(0.10)	(0.06)	(0.09)	(0.06)
RMSE	0.82	0.38	0.64	0.43	0.38	0.64	0.52	0.35	0.52	1.00	4.74	0.39	0.56	0.43	0.62	0.48

Sample 1985-2006. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2: Threshold Estimates with Regime Specific Intercepts

Inflation	Aut	Can	Den	Ger	Ire	Ita	Kor	Mex	Net	Spn	Swz	UK
Lag Inf	0.868***	0.796***	0.810***	0.816***	0.860***	1.071***	0.909***	1.180***	1.037***	0.802***	1.067***	1.002***
	(0.08)	(0.08)	(0.13)	(0.07)	(0.07)	(0.06)	(0.05)	(0.08)	(0.06)	(0.08)	(0.05)	(0.05)
Avg Lag	-0.078	-0.272 **	0.046	-0.075	-0.071	-0.101*	-0.202**	-0.204**	-0.141**	0.023	-0.177***	-0.170***
	(0.07)	(0.11)	(0.11)	(0.10)	(0.05)	(0.06)	(0.08)	(0.08)	(0.05)	(0.07)	(0.05)	(0.06)
Regime 1 (Open $\leq \theta_0$ ***)***												
Constant	0.543***	1.932***	0.322**	0.534*	0.657***	0.041	2.161***	-0.934	-0.549***	1.027***	0.315***	0.792***
	(0.16)	(0.47)	(0.14)	(0.27)	(0.15)	(0.14)	(0.44)	(2.36)	(0.12)	(0.33)	(0.08)	(0.20)
Dom Gap	0.216**	0.042	0.161**	0.172	-0.020	0.227*	-0.109	3.286**	-0.367***	-0.069	-0.012	0.120**
	(0.09)	(0.10)	(0.08)	(0.23)	(0.04)	(0.13)	(0.07)	(1.58)	(0.09)	(0.11)	(0.05)	(0.06)
For Gap	0.077	0.151	-0.082	-0.224	0.057	-0.204	0.449	1.567	-0.500***	0.269*	0.190*	0.415**
	(0.07)	(0.21)	(0.10)	(0.20)	(0.06)	(0.22)	(0.16)	(1.59)	(0.08)	(0.15)	(0.09)	(0.15)
Regime 2 (Open $> \theta_0$)												
Constant	0.471***	0.889***	0.311**	0.353***	0.740***	0.109*	1.060***	0.965	0.248**	0.476**	-0.367*	0.632***
	(0.13)	(0.22)	(0.13)	(0.12)	(0.18)	(0.06)	(0.26)	(0.66)	(0.10)	(0.18)	(0.18)	(0.19)
Dom Gap	-0.136	0.172 **	-0.105	-0.096*	0.011	-0.022	0.014	-0.391	-0.039	0.016	0.597**	0.161**
	(0.12)	(0.07)	(0.07)	(0.05)	(0.10)	(0.04)	(0.09)	(0.29)	(0.07)	(0.20)	(0.27)	(0.07)
For Gap	0.221**	-0.123	0.182**	0.265***	0.493***	0.101*	0.263*	0.399*	0.191**	0.125	-0.450	-0.199
	(0.10)	(0.12)	(0.08)	(0.09)	(0.18)	(0.06)	(0.15)	(0.23)	(0.09)	(0.14)	(0.19)	(0.12)
Threshold	0.648	0.501	0.497	0.446	1.041	0.303	0.500	0.216	0.749	0.354	0.636	0.394
F-Stat	2.74	5.39	4.21	2.10	4.89	2.43	4.17	4.64	5.37	2.73	3.84	4.02
p-value	0.06	0.00	0.00	0.18	0.00	0.01	0.01	0.00	0.03	0.06	0.01	0.00

Table A3: Threshold Estimates for De-Trended Inflation

Inflation	Aut	Can	Den	Ger	Ire	Ita	Kor	Mex	Net	Spn	Swz	UK
Constant	-0.047	-0.109	-0.143***	-0.101	-0.140*	-0.188***	0.053	0.347	0.004	-0.189**	0.002	-0.030
	(0.05)	(0.07)	(0.05)	(0.07)	(0.07)	(0.07)	(0.10)	(0.49)	(0.05)	(0.10)	(0.05)	(0.07)
Lag Inf	0.860***	0.720***	0.822***	0.795***	0.915***	1.020***	0.959***	1.125***	0.993***	0.723***	1.007***	0.932***
	(0.08)	(0.08)	(0.12)	(0.07)	(0.06)	(0.05)	(0.06)	(0.07)	(0.06)	(0.07)	(0.05)	(0.05)
Avg Lag	-0.136*	-0.166**	-0.032	-0.072	-0.129**	-0.175***	-0.168**	-0.204***	-0.137**	0.075	-0.198***	-0.181***
	(0.07)	(0.08)	(0.11)	(0.1)	(0.05)	(0.06)	(0.08)	(0.07)	(0.06)	(0.07)	(0.05)	(0.06)
	Regime 1 (Open $\leq \theta_0$ ***)***											
Dom Gap	0.240***	-0.138	0.125*	0.206	-0.002	0.224*	0.092**	4.343***	0.142	-0.692*	-0.026	0.153***
	(0.09)	(0.15)	(0.08)	(0.3)	(0.04)	(0.13)	(0.04)	(1.56)	(0.25)	(0.30)	(0.05)	(0.04)
For Gap	0.084	0.457	-0.090	-0.220	0.042	-0.153	0.253	-0.679	-0.191	1.260*	0.278***	0.102
	(0.07)	(0.35)	(0.10)	(0.30)	(0.07)	(0.20)	(0.16)	(1.77)	(0.19)	(0.33)	(0.09)	(0.08)
	Regime 2 (Open $> \theta_0$)											
Dom Gap	-0.062	0.220***	-0.086	-0.123***	-0.095	-0.052	0.102	-0.532	-0.026	0.122	0.055	0.062
	(0.10)	(0.07)	(0.08)	(0.04)	(0.12)	(0.04)	(0.12)	(0.29)	(0.07)	(0.08)	(0.09)	(0.27)
For Gap	0.163*	-0.048	0.146*	0.291***	0.787***	0.110*	0.160	0.834**	0.202**	0.040	-0.139	0.039
	(0.09)	(0.12)	(0.09)	(0.09)	(0.31)	(0.06)	(0.17)	(0.34)	(0.09)	(0.08)	(0.09)	(0.25)
Threshold	0.646	0.447	0.497	0.439	1.241	0.303	0.535	0.201	0.734	0.236	0.592	0.429
F-Stat	3.37	3.53	5.39	2.25	5.19	5.19	1.76	11.06	2.66	5.86	5.51	4.91
p-value	0.00	0.00	0.01	0.08	0.00	0.00	0.12	0.00	0.03	0.01	0.00	0.02

Inflation is determined as CPI inflation minus its exponentially smoothed trend component.

Table A4: Threshold Estimates with Real Exchange Rates

Inflation	Aut	Can	Den	Ger	Ire	Ita	Kor	Mex	Net	Spn	Swz	UK
Constant	0.492***	0.389**	0.225*	0.525***	0.520***	0.050	0.635***	0.444	0.227**	0.393**	0.052	0.516***
	(0.17)	(0.18)	(0.13)	(0.15)	(0.18)	(0.06)	(0.23)	(0.46)	(0.11)	(0.18)	(0.07)	(0.17)
Lag Inf	0.871***	0.909***	0.794***	0.678***	0.881***	1.054***	0.948***	1.209***	1.025***	0.857***	1.097***	1.012***
	(0.08)	(0.07)	(0.12)	(0.09)	(0.08)	(0.06)	(0.06)	(0.07)	(0.06)	(0.08)	(0.05)	(0.05)
Avg Lag	-0.076	-0.038	0.093	-0.055	-0.062	-0.073	-0.072	-0.203***	-0.120*	0.053	-0.148***	-0.140**
	(0.08)	(0.08)	(0.11)	(0.09)	(0.05)	(0.06)	(0.07)	(0.07)	(0.06)	(0.08)	(0.05)	(0.06)
	Regime 1 (Open$\leq \theta_0$)											
Dom Gap	0.213**	0.147**	0.216***	0.235	-0.014	0.216*	-0.064	0.944*	0.204	0.034	-0.159**	0.124***
	(0.09)	(0.06)	(0.07)	(0.36)	(0.04)	(0.14)	(0.04)	(0.49)	(0.19)	(0.11)	(0.07)	(0.05)
For Gap	0.056	-0.071	-0.102	-0.652	0.086	-0.202	0.198	0.786	-0.103	0.119	0.234**	0.133
	(0.09)	(0.12)	(0.08)	(0.41)	(0.07)	(0.22)	(0.18)	(1.00)	(0.16)	(0.19)	(0.1)	(0.09)
Real Exch	0.002	-0.025*	-0.033***	0.099**	0.006	-0.027	-0.004	-0.343***	-0.078***	-0.001	0.017*	-0.014
	(0.01)	(0.01)	(0.01)	(0.04)	(0.01)	(0.02)	(0.02)	(0.07)	(0.02)	(0.02)	(0.01)	(0.01)
	Regime 2 (Open$> \theta_0$)											
Dom Gap	-0.158	-0.329	-0.110	-0.073	-0.117	0.022	0.186**	-0.145	-0.043	-0.173	0.095*	-0.024
	(0.11)	(0.17)	(0.06)	(0.05)	(0.12)	(0.04)	(0.09)	(0.24)	(0.07)	(0.21)	(0.06)	(0.22)
For Gap	0.241**	0.656*	0.161**	0.275***	0.727***	0.063	0.333**	0.510***	0.182**	0.290**	-0.074	-0.033
	(0.10)	(0.35)	(0.08)	(0.1)	(0.23)	(0.06)	(0.17)	(0.2)	(0.09)	(0.15)	(0.06)	(0.22)
Real Exch	0.000	0.051*	-0.016	-0.023**	-0.050**	-0.018***	-0.053***	-0.105***	-0.001	0.021	-0.017*	0.026
	(0.02)	(0.03)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.03)	(0.01)	(0.03)	(0.01)	(0.02)
Threshold	0.648	0.696	0.497	0.397	1.224	0.302	0.535	0.252	0.749	0.354	0.530	0.423
F-Stat	2.45	2.85	5.71	7.56	4.54	6.50	3.57	6.02	3.58	2.52	3.33	5.11
p-value	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.01

Table A5: Threshold Estimates with Import Prices

Inflation	Aut	Can	Den	Ger	Ire	Ita	Kor	Mex	Net	Spn	Swz	UK
Constant	0.318**	0.13	0.187	0.214	0.384***	0.034	0.409*	-0.067	0.204*	0.62***	0.079	0.591***
	(0.15)	(0.17)	(0.11)	(0.17)	(0.14)	(0.07)	(0.25)	(0.37)	(0.11)	(0.21)	(0.07)	(0.21)
Lag Inf	0.872***	0.853***	0.759***	0.773***	0.962***	1.029***	0.964***	1.174***	1.02***	0.902***	0.998***	0.986***
	(0.08)	(0.08)	(0.12)	(0.13)	(0.06)	(0.05)	(0.06)	(0.04)	(0.06)	(0.08)	(0.06)	(0.05)
Avg Lag	-0.019	0.071	0.126	0.053	-0.088*	-0.041	-0.079	-0.145***	-0.119*	-0.072	-0.038	-0.13**
	(0.07)	(0.09)	(0.1)	(0.16)	(0.05)	(0.05)	(0.07)	(0.04)	(0.06)	(0.07)	(0.06)	(0.06)
					Regime 1 (Open $\leq \theta_0$ ***)***							
Dom Gap	0.248***	0.064	0.153**	0.115	-0.021	0.024	0.098	-18.039***	0.169	0.294***	-0.127	0.116***
	(0.1)	(0.1)	(0.08)	(0.7)	(0.05)	(0.06)	(0.07)	(6.97)	(0.23)	(0.09)	(0.14)	(0.04)
For Gap	0.011	0.011	-0.127	0.098	-0.141	-0.034	0.083	-5.449***	-0.224	-0.119	0.169	0.096
	(0.1)	(0.2)	(0.1)	(0.84)	(0.12)	(0.1)	(0.14)	(2.16)	(0.18)	(0.11)	(0.12)	(0.11)
Imports	0.005	0.005*	-0.001	-0.027	0.006*	0.012***	0.004	0.496***	0.007**	0.003	0.011**	0.001
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.15)	(0.03)	(0.05)	(0.04)	(0.02)
					Regime 2 (Open $> \theta_0$)							
Dom Gap	-0.176*	0.060	-0.109	-0.086*	-0.022	0.039	-0.131	-0.334	-0.026	-0.306	0.055	-0.276
	(0.09)	(0.07)	(0.06)	(0.05)	(0.05)	(0.04)	(0.15)	(0.23)	(0.07)	(0.23)	(0.06)	(0.26)
For Gap	0.239***	-0.154	0.119*	0.146*	0.167***	0.049	0.907*	0.414*	0.173*	0.320**	-0.041	0.554
	(0.08)	(0.13)	(0.07)	(0.09)	(0.05)	(0.07)	(0.53)	(0.27)	(0.09)	(0.14)	(0.06)	(0.36)
Imports	0.003***	0.008***	0.003***	0.004***	0.005***	0.001*	0.037**	0.011	0.000	0.002*	0.002***	-0.023**
	(0.01)	(0.03)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Threshold	0.6317	0.5766	0.4967	0.3769	0.9009	0.3544	0.6698	0.1975	0.7491	0.3536	0.5064	0.4291
F-Stat	3.83	5.02	6.30	3.05	2.59	8.43	2.76	15.46	3.34	9.87	6.40	3.90
p-value	0.00	0.01	0.00	0.02	0.02	0.00	0.03	0.00	0.13	0.00	0.00	0.06

Table A6: Threshold Estimates for Core Inflation

Inflation	Aut	Can	Den	Ger	Ire	Ita	Kor	Mex	Net	Spn	Swz	UK
Constant	0.322***	0.223*	0.149**	0.095	0.681***	0.058	0.493***	-0.345	0.194**	0.516**	0.117**	0.109
	(0.10)	(0.12)	(0.06)	(0.11)	(0.17)	(0.07)	(0.17)	(0.70)	(0.09)	(0.21)	(0.06)	(0.11)
Lag Inf	0.788***	0.929***	0.941***	0.951***	0.883***	0.953***	0.991***	1.19***	1.093***	0.653***	1.101***	0.957***
	(0.08)	(0.06)	(0.1)	(0.08)	(0.07)	(0.08)	(0.07)	(0.06)	(0.06)	(0.13)	(0.06)	(0.06)
Avg Lag	0.076	-0.011	-0.018	0.004	-0.078	0.020	-0.106	-0.112	-0.183**	0.211**	-0.140**	-0.003
	(0.08)	(0.05)	(0.09)	(0.11)	(0.05)	(0.08)	(0.09)	(0.07)	(0.08)	(0.09)	(0.06)	(0.07)
						Regime 1 (Open $\leq \theta_0$)						
Dom Gap	0.456***	-0.018	0.121***	0.115	0.007	0.130*	0.087*	14.29***	0.031	0.120	-0.114	0.163***
	(0.08)	(0.09)	(0.05)	(0.15)	(0.04)	(0.08)	(0.06)	(2.73)	(0.05)	(0.1)	(0.09)	(0.06)
For Gap	-0.023	0.211	-0.036	0.076	0.048	0.024	-0.067	-2.783	0.009	0.194	0.334***	-0.098
	(0.07)	(0.15)	(0.06)	(0.29)	(0.06)	(0.11)	(0.21)	(3.22)	(0.06)	(0.11)	(0.11)	(0.10)
						Regime 2 (Open$> \theta_0$)						
Dom Gap	-0.160	0.098**	-0.053	-0.028	0.002	0.032	0.014	-0.551	-0.124	-0.118	0.056	-0.078
	(0.11)	(0.04)	(0.04)	(0.03)	(0.10)	(0.04)	(0.07)	(0.37)	(0.13)	(0.16)	(0.04)	(0.28)
For Gap	0.302***	0.184**	0.082*	0.090*	0.529***	0.005	0.295***	0.815*	0.349**	0.278***	0.001	0.29
	(0.10)	(0.09)	(0.04)	(0.05)	(0.21)	(0.06)	(0.10)	(0.42)	(0.14)	(0.11)	(0.05)	(0.23)
Threshold	0.629	0.604	0.497	0.423	1.041	0.313	0.497	0.198	1.036	0.354	0.506	0.423
F-Stat	12.52	2.15	4.93	5.51	7.03	2.97	4.71	7.39	2.20	3.37	4.58	3.54
p-value	0.00	0.09	0.00	0.00	0.00	0.01	0.02	0.00	0.08	0.12	0.00	0.10

Inflation is determined as the four quarter change in the CPI excluding food and energy prices.

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4 Chapter 3

A dynamic panel threshold analysis of the inflation globalization hypothesis

Abstract

Previous studies on the inflation globalization hypothesis have examined this question primarily at the individual-country level. However, a panel approach seems quite appropriate as globalization measures, such as trade openness, often exhibit considerable cross-sectional variation. We thus investigate the relationship between inflation and globalization, under an open-economy Phillips Curve framework, for a panel of OECD countries with the dynamic panel GMM methodology developed in Arellano and Bond (1991). Using this framework, we find strong evidence in favor of including global factors, represented by the foreign output gap, in a country's inflation process. We further augment the dynamic panel model with a threshold component(Hansen, 1999), and so are able to identify regions of stronger responsiveness of inflation to global factors. Based on our non-linear analysis, we show that trade openness acts as a threshold variable for the effects of domestic and foreign slack on inflation. Importantly, the switch in the output gap slopes from one regime to the other is consistent with the key predictions of the inflation globalization hypothesis, so that in more open economies the foreign output gap replaces the domestic output gap as the key determinant in the country's domestic inflation process.

4.1 Introduction

Globalization has served as a catalyst for substantial changes in the behavior and functioning of the modern economy. An area that has seen considerable emphasis and discussions, both in policy and research circles, is the impact globalization, in the form of increased level of international trade in goods and services, can have on the domestic inflation process. One prominent view, known as the inflation globalization hypothesis, holds that highly interconnected markets will allow external factors to eventually replace the domestic determinants of inflation, so that local prices are guided primarily by global markets. Not surprisingly, this has very significant policy implications as it would leave inflation untethered from traditional monetary policy channels and could ultimately lead to changes in the way monetary policy is conducted. It is thus essential to evaluate the validity of the inflation globalization hypothesis and determine the exact role globalization plays in a country's inflation dynamics. Our paper shows that by adequately accounting for heterogeneity across countries as well as allowing globalization to effect inflation non-linearly, we are able to see strong evidence in favor of the inflation globalization hypothesis.

The inflation globalization hypothesis is a radical departure from the traditional view of inflation dynamics being a function of inflation expectations and the current level of economic slack or resource utilization in the domestic economy. While monetary policy is still expected to influence inflation in the long run, the inflation globalization hypothesis allows foreign factors such as the level of global slack to play the dominant role in the short run dynamics. This is also in contrast to those who believe that globalization and increased competition has been a contributing factor in reducing inflation rates around the world (Kamin et al. 2006), but without changing the underlying inflation process (Pain et al., 2006). The validity of the inflation globalization hypothesis would lead to fundamental changes in how inflation is modeled going forward along and force policy makers to place emphasis on global conditions.

A number of studies have examined the key prediction of the inflation globalization hypothesis that the role of the foreign output gap in the determination of the domestic inflation increases at the expense of the domestic output gap as a country becomes more integrated. This prediction is usually tested in the context of the Phillips Curve, which has been the workhorse model for inflation dynamics. The empirical findings however, have been mixed, with little consensus on the importance of the foreign output gap and thus globalization in a country's inflation process. Borio and Filardo (2007) highly cited findings show that including a measure of foreign slack in a reduced Philips Curve framework is appropriate for every country in their sample. On the other hand, Ihrig et al. (2010) illustrate that these results don't hold when a more traditional approach to inflation expectations is employed in the analysis.

We continue this line of inquiry but move away from the existing literature in two key aspects. First, we rely on a panel analysis to investigate the relationship between foreign output gap and inflation. Most of the previous work looks at this relationship at the individual-country level and the panel methods, if used, are often very basic and supplementary. However, a panel approach seems quite relevant as globalization measures such as trade openness exhibit considerable cross-sectional variation as compared to within country variation. Indeed, Bianchi and Civelli (2015) found some preliminary evidence that the effect of the global economic slack on inflation is positively related to the degree of openness for a panel of countries.

The second and main contribution of our paper is that we explicitly allow a country's level of trade openness, used here as a proxy of the country's degree of globalization, to act as a threshold variable in the inflation process. We can then determine the empirical relevance of a threshold effect of trade openness in our panel framework, such that inflation responds to external factors only after a certain level of openness has been achieved by a country. A number of economic factors can cause globalization to have a non-linear effect in the inflation process. For instance, Sbordone (2007) has shown that one of the ways globalization can affect the structural determinants of inflation is by reducing the market power of domestic sellers through increased competition; however, it may be the case that domestic companies only start to pay attention to foreign competitors after they have reached a significant level of market share. At the individual country level, Ahmad and Civelli (2015) have examined this non-linearity for a sample of OECD countries and have shown that for some countries the observed changes in openness are just not large enough to actually induce structural breaks in the inflation dynamics. Thus the potential of non-linearity should not be omitted from any analysis of the inflation globalization hypothesis, and by further exploring it in a panel framework, we are able to exploit the cross-sectional variation in openness to identify the regions where inflation responds strongly to foreign factors. Overall, our flexible modeling approach should provide greater insight on the relationship between inflation and openness.

For our empirical analysis, we rely primarily on the dynamic panel GMM methodology developed in Arellano and Bond (1991), which provide consistent and efficient estimates of the panel model in the presence of lagged dependent variables. Thus the Arellano and Bond (1991) framework is very convenient to incorporate inflation dynamics that are given by a backward-looking Philips Curve model. In our analysis, we concentrate on the backward-looking Philips Curve specification as it has been shown to be a better empirical fit in capturing inflation dynamics (Rudd and Whelan, 2007). However, this methodology can be extended to embed the New Keynesian Phillips Curve models, developed by Galı and Gertler (1999), and so we will also examine a model that is consistent with a structural interpretation of the inflation globalization hypothesis. Finally to augment the dynamic panel model with a threshold component, we follow the recent contributions by Caner and Hansen (2004) and

Kremer et al. (2013), that gives consistent estimates of the threshold for panel data even in the case of endogenous regressors. Thus our paper is also part of the new empirical literature that analyzes threshold behavior in a dynamic panel setting.

Our dynamic panel Philips Curve model is employed on the entire group of OECD countries for the period 1970-2013. Two important results emerge from our estimates. First, we see strong evidence that the foreign output gap is statistically significant and of the same magnitude as the domestic output gap in the country's inflation process. These results also hold when we account for instrument proliferation in the dynamic panels and the possibility of endogenous explanatory variables. Our main findings are also not affected either by the inclusion of traditional controls such as movement in the real exchange rate, or by restricting the sample period to control for clear changes in monetary policy regimes.

The second key finding of our analysis is that there is significant evidence of non-linearity in our dynamic panel Phillips curve framework with countries seeing a meaningful shift in their inflation dynamic once a level of openness is reached. Crucially, the switch in the output gap slopes from one regime to the other is consistent with the key predictions of the inflation globalization hypothesis in that the foreign output gap coefficient increases and switches from non-significant to significant in the more open regime, while the domestic output gap coefficient moves in the opposite direction and loses significance in the more open regime. Thus the estimated 90% confidence interval of $[35 - 57]$, for the openness threshold value, can be used by policy makers as a guide on when to direct their attention to the influence of external forces in the inflation process.

The chapter is organized as follows. In Section 4.1.1 we review the current literature with regards to the inflation globalization hypothesis. Section 4.2 looks at the motivation of a panel approach and its validity. In Section 4.3 we discuss the main findings of the dynamic panel analysis while Section 4.4 examines the panel threshold model. Section 4.5 concludes.

4.1.1 The relationship between globalization and inflation

The traditional approach in modeling inflation dynamics has been to focus on country-specific factors, such as domestic output, while assigning a limited role to external factors, usually in the form of supply shocks. However, the increased level of globalization that has taken place in recent years in the form of greater openness to trade, financial integration, and higher mobility across factor markets might have very well changed the nature of the inflation process. So it may now be the case that domestic prices in highly integrated economies are influenced more by global markets, rather than local markets.

Clarida et al. (2002) and Gali and Monacelli (2005) extend the micro-founded New Keynesian Phillips Curve for the case of an open economy with sticky prices, and this has quickly become the workhorse model in the open-economy modeling literature.[1] One of the key insights of this model is that domestic inflation now depends on the weighted average of the domestic and foreign output gaps, where the weights represent some preference for home goods.[2] The inclusion of the foreign output gap in the Phillips Curve shows that along with the direct effects of trade on the price level, such as deviations in the import prices or the real exchange rate, there is also a need for some measure of excess global demand, since low demand in one country could be countered by high demand in another. In the extreme, as pointed out by Borio and Filardo (2007), this implies that excess demand should actually be aggregated at the product rather than the country level.

Another strong implication of this modeling framework is that as economies become more open, the traditional relation between short-run inflation and the domestic output gap weak-

[1]This framework was used by Corsetti and Pesenti (2005) and Gali and Monacelli (2008) to analyze how openness affects optimal monetary policy.

[2]Zaniboni (2008) showed that this holds for different assumptions on the pricing behavior of the exporting firms.

ens, leading to the flattening of the Phillips Curve (Zaniboni, 2008). Sbordone (2007) and Razin and Binyamini (2007) have shown that the diminishing sensitivity of inflation to domestic output fluctuations can be associated with increased globalization, as the greater competition in goods and factors of production reduces the market power of domestic sellers. A flatter Phillips Curve also effects monetary policy as it becomes more costly to bring inflation to desired target levels.[3] Overall, this modeling framework has clear predictions for the response of inflation to the domestic and foreign output gaps that can be tested to determine the relationship between globalization and inflation.

4.1.2 Empirical Evidence

A general expression of the reduced form open-economy New Keynesian Phillips Curve model in Clarida et al. (2002) can be given as

$$\pi_t = \alpha E_t \pi_{t+1} + \beta Y_t^d + \gamma Y_t^f + \varepsilon_t \tag{1}$$

where π_t is inflation, $E_t\pi_{t+1}$ is the expected inflation next period, Y_t^d and Y_t^f are the current domestic and foreign output gaps, respectively.[4] Generally, in the empirical literature, lags of inflation are used as a proxy for $E_t\pi_{t+1}$ so that equation (1) becomes purely backward-looking. While the resultant model lacks a structural interpretation, it still provides a suitable reduced-form analysis of the underlying inflation dynamics. Further, there is strong evidence that when compared with forward-looking models the backward looking model is actually a better empirical fit (Rudd and Whelan, 2007) and also more structurally stable

[3]Razin and Binyamini (2007) argues that this leads monetary authorities to become more aggressive toward inflation and reduce the weight on the domestic output gap.

[4]See Martinez-Garcia and Wynne (2010) for a micro-founded derivation of equation (1).

(Estrella and Fuhrer, 2003). Lastly, it is also common in this analysis to add controls for import prices or the terms of trade to capture the direct impact of trade on the price level.

A number of studies have used a model similar to equation (1) to investigate the inflation globalization hypothesis and the role of the foreign output gap in the inflation process.[5] For equation (1), the inflation globalization hypothesis implies declining estimates of β and conversely higher magnitudes of γ as a country is integrated in the global economy. The empirical evidence on the inflation globalization hypothesis, however, is quite ambiguous, and there is still considerable debate on the validity of including the foreign output gap as a determinant in a country's inflation dynamics.

Borio and Filardo (2007) show that for a sample of 16 OECD economies, the foreign output gap is statistically significant in explaining inflation and that these findings hold for different measures of the foreign output gap. Gamber and Hung (2001) show that globalization in the late 90s increased the sensitivity of U.S. inflation to foreign economic condition. Wynne and Kersting (2007) also find similar evidence that global slack matters for the U.S. inflation process. Furthermore, the IMF (2006) found that increased globalization has led to a reduction in sensitivity of inflation to domestic capacity for a group of advanced economies.[6]

Ihrig et al. (2010) reexamine the findings of Borio and Filardo (2007) and show that the foreign output gap becomes insignificant when more traditional proxies for expected inflation

[5] It is important to distinguish the studies on the inflation globalization hypothesis from another strand that focuses solely on the direct impact on inflation from imports, especially imports from developing countries (Kamin et al., 2006). These have generally found that, at least in the case of advanced economies, import prices have only a modest downward impact on domestic inflation (Pain et al. (2006), IMF, 2006).

[6] On the other hand, Ihrig et al. (2010) find little evidence that this decline was due to increased globalization. Using a state-space framework, López-Villavicencio and Saglio (2014) also determine that openness is not responsible for the flattening of the Philips curve in the cases of the U.S., France and the U.K.

such as π_{t-1} and earlier lags are instead used in these estimations.[7] Calza (2009) also finds that global output gaps have little success in explaining domestic inflation for the Euro area as a whole. Using a structural model for the G7 countries, Milani (2010) determines that global output impacts domestic inflation only indirectly and thus should not be included in the Phillips Curve specification. Finally, Bianchi and Civelli (2015), employing a time-varying VAR model, show that for most countries in their sample, the effects of the foreign output gap on inflation are comparable to those of the domestic output gap, but these effects have not grown over time.

4.2 A Panel Approach

The preceding empirical evidence on the inflation globalization hypothesis is primarily based on analysis at the individual-country level. One of our main goals in this paper is to properly account for variation in inflation and openness across countries and then use this variability to evaluate the inflation globalization hypothesis. A panel approach blends the inter-country differences with the intra-country dynamics, enabling a more complete picture to emerge.

4.2.1 Data and Motivation

For our analysis, we expand on the dataset used in Bianchi and Civelli (2015) to all of the 28 OECD countries with annual data from 1970 to 2013.[8] As is the standard in this literature, we use the Consumer Price Index (CPI) as our measure of the domestic price level with inflation the year-to-year change in the CPI. Trade openness is calculated as exports plus

[7] In particular, Borio and Filardo (2007) used the trend of core inflation as a proxy for inflation expectations which, as discussed in Ihrig et al. (2010), causes the residuals to become auto-correlated and the model misspecified.

[8] Poland and Chile were excluded from our analysis because both of these countries experienced bouts of hyperinflation during this time frame.

imports over GDP with all the values in nominal terms. The domestic output gap for each country is calculated using an HP filter on the real GDP series (we account for the end-of-sample problem by forecasting the real GDP five years ahead before applying the filter). As in Bianchi and Civelli (2015), the foreign output gap and the effective real exchange rate are calculated by weighting the trading partners of each country.[9] The foreign output gap for a country is then just the trade-weighted average of the domestic output gaps of all the other countries in our sample. Similarly, the effective real exchange rate index is given by the geometrically trade-weighted average of the pairwise real exchange rate.

Figure 1 shows the evolution of trade openness for the individual countries in this sample period. We observe significant variation with relatively closed economies such as the U.S. and Japan at one end of the spectrum while more open economies such as Netherlands and Ireland on the other end. We see similar variation in Table 1, which gives us the summary statistics for all of the variables pooled across country and years for a total of 1,232 observations.[10] For each of these variables, we determine both its within standard deviation s_w (measures the variability across time) and its between standard deviation s_B(measures the variability across countries).[11] As seen in Table 1 the between deviation for trade openness is nearly twice the value of the within deviation, indicating that there is substantially more variation in openness between countries than over time. Indeed, one of the main issues with analyzing the inflation globalization hypothesis at the country level is that some countries, during the sample period, may not experience changes in their level of openness large enough to induce clear breaks in the relation between inflation and the foreign output gap. So a single-country

[9]To get accurate trade weights we included more than 70 other countries to our sample universe. The list of countries and details on the trade weights are in the appendix 4.6.1.

[10]Te reduce the size of the panel in the dynamic panel analysis, we will concentrate on the three-year averages of the Phillips Curve variables discussed in Table 1.

[11]These are calculated as $s_W^2 = \frac{1}{NT-N}\sum_{i=1}^{N}\sum_{t=1}^{T}(z_{it}-\bar{z}_i)^2$ and $s_B^2 = \frac{1}{N-1}\sum_{i=1}^{N}(\bar{z}_i-\bar{z})^2$ for $1 < i < N$ and $1 < t < T$

analysis is often an unsatisfactory tool to assess the true impact of openness on inflation. A panel analysis, on the other hand, can use the cross-country variation in openness to better capture the relationship between inflation and globalization. Finally, for the other variables, including inflation, much of the underlying variation is a result of changes over time.

Table 1: Summary Statistics (1970-2013)

Variable	Mean	Std Dev	Within	Between	Min	Max
Inflation	9.60	20.96	18.45	14.08	-4.48	73.82
Openness	45.70	21.02	10.65	18.18	5.43	151.04
Dom Gap	0.02	4.56	4.60	0.20	-21.76	18.62
For Gap	0.40	2.47	2.50	0.21	-4.91	10.83
Real Exch Rate	0.25	6.20	6.24	0.57	-32.66	32.38

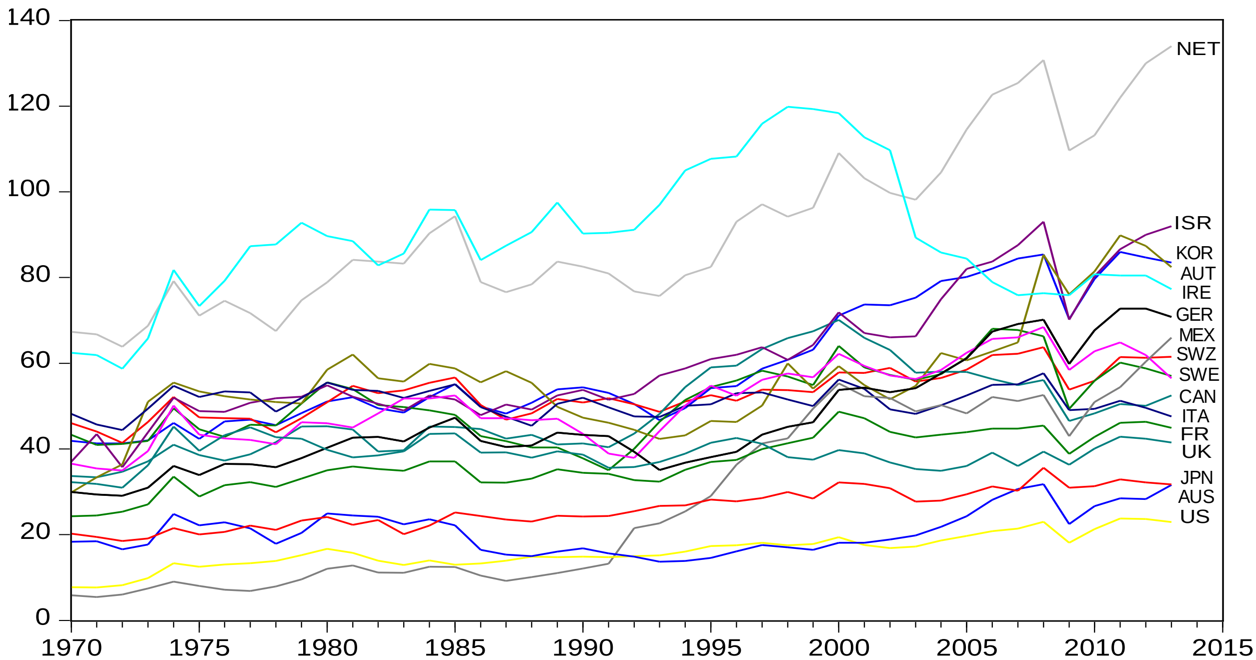

Figure 1: Evolution of the Trade Openness measure for the OECD countries (1970-2013)

The estimates of the individual Phillips Curve model given by equation (1), provide additional support for utilizing cross-sectional differences in openness to help understand the role of globalization in the inflation process.[12] Figure 2 shows the estimates of the foreign output gap coefficient for each country plotted against its average level of openness. We see that the countries with higher levels of openness are more likely to have a significant role for the foreign output gap in their inflation process. Such a finding is consistent with the inflation globalization hypothesis of a positive relation between globalization and the effects of global economic slack on inflation. Figure 2 also indicates the potential of non-linearity in the relationship between inflation and globalization, with a country having to achieve some level of openness for the foreign output gap to matter in the inflation process. We will analyze the possibility of such threshold behavior in Section 4.4.

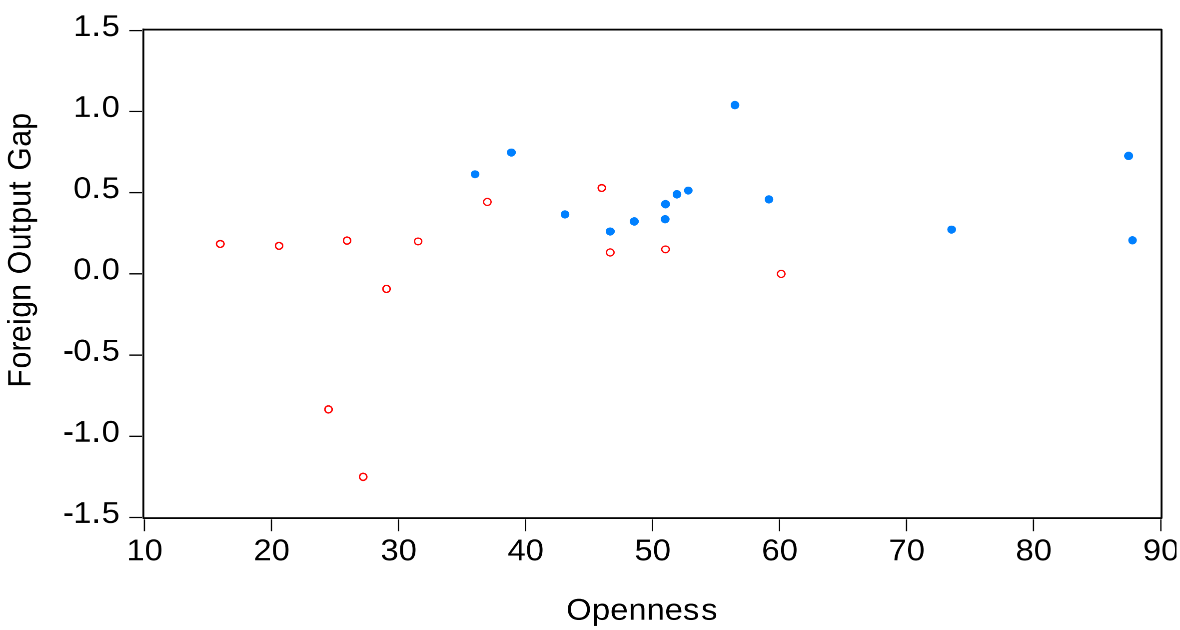

Figure 2: Individual Foreign Gap estimates along with the average level of openness.

[12]As in Ihrig et al. (2010) we use π_{t-1} as a proxy for $E_t\pi_{t+1}$ in these estimations.

4.2.2 Is a Panel Analysis Valid?

Before embarking on the panel analysis, we need to make sure that a panel approach is actually valid for our dataset. In particular, we address the validity of having the same slope coefficients across the countries as well as the potential of exhibiting a unit root process.

In standard panel treatments, the assumption is that the slope coefficients are constant across cross-sections with allowances made for varying intercepts to capture some of this cross-sectional as well as time-specific heterogeneity (treated as either fixed or random effects). But this assumption of poolability may not hold in a dynamic panel, especially with large N and T, and so needs to be explicitly tested for in the analysis (Pesaran and Smith, 1995).

For relatively small N, the F-test can be used to test for poolability with the constant slope assumption treated as a linear restriction on the N individual equations given by (1) ($B_i = B$ $\forall\, i$). Two variants of the F-test are available depending on the variance-co variance structure of the disturbance vector $\varepsilon = [\varepsilon_1^{'}, \varepsilon_2^{'}, ...\varepsilon_N^{'}]'$, where the ε_i are the individual $Tx1$ error terms. If these disturbances are assumed to be conditionally homoscedastic so that $E[\varepsilon'\varepsilon] = \sigma^2 I_{NT}$, then the standard F-test can be applied, with each of the N equations in the unrestricted model estimated separately by OLS. Alternatively, a Roy-Zellner test as in the Seemingly Unrelated Regressions (SUR) framework (Zellner, 1962) can also be applied so that there is a possibility of both heteroscedasticity and contemporaneous cross-correlations among the individual disturbances. Bun (2004) has shown that the finite sample performance of these tests is actually quite poor (a strong tendency to over-reject) in panel models with lagged dependent variables and so need a bootstrap procedure to get accurate p-values.

Table 2 shows the results for the poolability tests conducted on equation (1) for our sample countries. We see from the simple F-tests that the null of poolability is not rejected for both the asymptotic and the bootstrapped p-values. Allowing for only the intercepts to vary (so the restricted case is then estimated by the Fixed Effects estimator) also does not impact these findings. We next turn to the Roy-Zellner test, which allows for the more realistic scenario of countries with hetroscedastic disturbances. In these tests, there is a strong difference between the asymptotic and the bootstrapped p-values, and so we have conflicting evidence on the suitability of pooling the slopes across countries. However, in a simulation study Bun (2004) showed that classical asymptotic tests in dynamic panels have substantial size distortions especially when used with a full disturbance covariance matrix. On the other hand, the bootstrap test performed well in these simulations. Thus, based on the high bootstrapped p-values in Table 2 we determine that pooling our data for 1 is appropriate. Finally, for robustness we also conducted a Hausman test as suggested in Pesaran et. al (1996) and again see a similar finding for poolability.[13]

Table 2: Testing for Poolability

	Statistic	p-value	
		classic	bootstrap
F-test (intercept and slopes)	1.08	0.27	0.41
F-test (slopes only)	1.09	0.27	0.35
Roy-Zellner test (intercept and slopes)	6.33	0.01	0.82
Roy-Zellner test (slopes only)	7.89	0.01	0.47
Hausman test	0.22	0.97	.

1000 repetitions used for the bootstrapped p-values.

As in the case of univariate analysis, unit roots can also lead to spurious regressions and misleading inference in a panel framework. This is especially a concern with inflation, which is often associated with high levels of persistence(Culver, 1997) . So in this section, we

[13]In the Hausman test we compare the Fixed Effect estimator with the Mean Group estimator as has been proposed by Pesaran and Smith (1995). Note that under the null of poolability the Fixed Effects will be more efficient, but in the alternate only the Mean Group is consistent. A non-rejection of the null then supports poolability of the data.

determine the stationarity of our panel series by applying some general panel unit root tests.

Table 3 gives the results of these panel unit root tests. We first consider the standard LLM test of Levin et al. (2002), which assumes a common autoregressive parameter for all countries as well as no correlation among the cross-sectional units, except for common time effects. We also account for cross-sectional correlation in these tests by using data demeaned from common time effects. Based on the LLM bias-adjusted t^*statistic, the null of unit root is rejected for all of our series. We then conduct the IPS test following Im et al. (2003) which, unlike the LLM test, allows for heterogeneous intercepts and slopes for each country. The results from the IPS test, controlling for serially correlated errors, are broadly similar, and we continue to find little evidence for a unit root in these panel series. Finally, we also conduct the Hadri (2000) LM test which instead tests for the null that the data are stationary and can be used in cases where N is not too large. Table 3 shows that the Hadri LM test is not able to reject the null of stationarity for all of these series. So based on these tests, we will continue to treat all of our variables including inflation as stationary in the empirical analysis. For a sample of OECD countries, Basher and Westerlund (2008) find inflation to be stationary even with panel unit root tests that allow for cross-sectional dependence and the possibility of structural change.

Table 3: Panel Unit Root Tests

	LLC test (common)		IPS test (individual)		Hadri test	
Null:	All panels have unit root		All panels have unit root		All panels stationary	
	t^*	p-value	W_t	p-value	Z_τ	p-value
Inflation	-2.78	0.00	-3.65	0.00	1.17	0.12
Openness	-1.78	0.03	-2.70	0.00	1.09	0.27
Dom Gap	-5.84	0.00	-8.40	0.00	-1.43	0.92
For Gap	-2.87	0.00	-4.19	0.00	2.74	0.03
Real Exch	-23.89	0.00	-24.30	0.00	1.00	0.16

Lag length selected based on BIC criteria. The tests assume asymptotic normality.

4.3 Dynamic Panel Analysis

4.3.1 Empirical Framework

We modify the individual country Philips Curve given in equation (1) to a panel framework and obtain the following dynamic panel model:

$$\pi_{it} = \rho\pi_{i,t-1} + \beta Y_{it}^{d} + \gamma Y_{it}^{f} + \eta_i + \varepsilon_{it} \tag{2}$$

where i is the country identifier, t is a period index, η_i is the country-specific error term, ε_{it} is the idiosyncratic shock, the lag term is a proxy for inflation expectations and the output gaps are defined as before. Due to the dynamic nature of the model, $\pi_{i,t-1}$ is endogenous in equation (2) as $E[\pi_{i,t-1}\eta_i] > 0$. The standard Fixed Effects (Within-Group) estimator also can not be used to eliminate η_i as it will be biased and, for small T, inconsistent as well (Nickell, 1981). One popular approach to eliminate the fixed effects η_i in a dynamic panel framework is to apply instead a first-difference transformation on (2)and then instrument the endogenous lag term. With predetermined initial conditions, $E[\pi_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$ for $s \geq 2$, $t = 3, .., T$, and so $\pi_{i,t-2}$ and earlier lags are valid instruments for $(\pi_{i,t-1} - \pi_{i,t-2})$. For a given set of instruments the estimation can be done by either 2SLS (Anderson and Hsiao, 1981) or General Method of Moments (GMM) with the GMM being more efficient when errors are not assumed to be independent (Arellano and Bond, 1991).[14]

[14] In our analysis we do not rely on the System GMM estimator, which uses an additional moment condition in the levels equation to estimate highly persistent series (Blundell and Bond (1998)). The System GMM, however, requires a much stronger assumption that the correlation between y_{it} and η_i is constant over time so that the deviations of the initial conditions from the steady state are uncorrelated with η_i, a condition that is not likely to hold in the case of a country's initial inflation levels.

The consistency of the GMM estimator requires that all the instruments used are valid, so having zero correlation with the error term. In our analysis, we will use two tests to determine the validity of the instruments in the dynamic panel GMM estimation. The first is the traditional Hansen (1982) J-test of over-identifying restrictions, with the null that the selected instruments are all exogenous. The Hansen test can also be extended to determine the validity of only a subset of the instruments, by looking at the difference in the J statistics when both the full and subset of instruments are used in the estimation. This difference follows a χ^2 distribution and so can be used to test the validity of the excluded instruments alone. While high p-values from the Hansen tests support the choice of instruments, a legitimate concern with this test is that it quickly becomes undersized once the number of instruments increases, as is often the case in dynamic panel estimations.[15]

We will also be using the Arellano and Bond (1991) serial correlation test to determine the appropriateness of the lagged terms as instruments in the difference equation (so for example $\pi_{i,t-2}$ is not a valid instrument for $(\pi_{i,t-1} - \pi_{i,t-2})$ if ε_{it} is serially correlated with $\varepsilon_{i,t-1}$). The Arellano and Bond (1991) test checks for the n^{th} order serial correlation in the levels equation by examining if the residuals of the differences equation are correlated at order $n+1$ (so tests if $\varepsilon_{it} - \varepsilon_{i,t-1}$ is actually correlated with $\varepsilon_{i,t-n} - \varepsilon_{i,t-n-1}$).[16] A failure to reject the null of no serial correlation for this test then supports the lags used as instruments in the dynamic panel estimation.

[15] Results of these tests are questionable once the instrument count exceeds N in the estimation (Roodman, 2009).

[16] In the case of an orthogonal transformation, this test is still applied on the differences equation since all the residuals, after the orthogonal transformation, will be interconnected with the forward observations.

4.3.2 First Results

Table 4 gives the estimates of the equation (2), while using the three-year averages for all the variables. Taking three-year averages, instead of annual values, ensures that we have a short panel with T (15 periods) smaller than N (28 countries) that can be efficiently estimated by the dynamic panel GMM estimator.[17] Such an approach has been commonly used in the empirical growth literature where usually five-year averages are taken to investigate growth relationships. However, for robustness we will in 4.3.4, also consider a panel estimation that employs only annual data.

The first two columns of Table 4 show the Pooled OLS (POLS) and Fixed Effect (Within Mean) estimates with robust standard errors clustered at the country level. The lagged inflation term is significant in both cases and, as expected from individual country Philips Curve estimates, quite large (0.82 and 0.70 respectively). However, due to the endogeneity of the lagged term, the Pooled estimate is going to be biased upward while the Fixed Effect estimate is going to be biased downward (Bond, 2002). The domestic gap is significant in both cases, but the foreign output gap is significant at the 10% level only in the Fixed Effect estimation. These output gap coefficients however, can also be biased depending on how correlated they are with the lagged inflation term.[18]

To eliminate the fixed effects η_i we next turn to the first-differences transformation. To control for endogeneity in the differences equation, the 2SLS estimator is initially used with the twice-lagged inflation term $\pi_{i,t-2}$ serving as the instrument for $\pi_{i,t-1}- \pi_{i,t-2}$ (just identified case). The estimates shown in the third column, though, are dramatically different as the

[17]By using three-year averages we in effect move away from the short-run fluctuations in inflation and so are better able to capture the impact of the gradual changes in openness.

[18]The foreign output gap is also significant when we use the Fixed Effect estimator on the annual data. A larger T dimension reduces the Fixed Effects bias and makes the estimates more reliable. See Appendix 4.6.2 for more details.

lagged inflation term now has a value greater than 1 (making the Phillips Curve unstable), and both the gaps are found to be insignificant. The issue, according to Roodman (2006), is that the 2SLS estimates are not accurate if the errors are not truly independent, as is the case for the differences equation ($\varepsilon_{it} - \varepsilon_{i,t-1}$ is correlated with $\varepsilon_{i,t-1} - \varepsilon_{i,t-2}$). Thus a GMM estimator is needed to account for the non-spherical error term in the differences equation.

Columns four and five in Table 4 show the GMM estimates of the first-differences equation in which all valid lags of inflation are used as instruments (a total of 94 instruments for each estimation). An issue that arises with GMM estimations in small samples is that the estimated standard errors are downward biased. Thus the early approach in the empirical dynamic panel literature, was to sacrifice efficiency and get consistent estimates of the standard errors by using the one-step GMM estimator.[19] Windmeijer (2005), however, has proposed a small-sample bias correction for the two-step GMM estimator which alleviate these concerns and enables more accurate inference. We employ both GMM estimators with the Windmeijer corrected standard errors and see they give identical results. The lagged inflation term has a coefficient of 0.74, a reasonable value falling between the earlier POLS and Fixed Effect estimates. Further, both gaps are significant with the foreign output gap larger than the domestic output gap. Finally, in column six we employ the forward orthogonal deviations instead of first-differences to eliminate the fixed effect term.[20] The benefit of this transformation is that if the error terms are independent then they remain so even after the transformations. The coefficients from the two-step GMM estimation are similar with now both the domestic and foreign output gaps significant at the 5% level. Thus switching from first-differences to orthogonal deviations does not impact the main results.

[19]Note that for the one-step GMM estimator, the weighting matrix does not depend on any estimated parameter, so making asymptotic approximations more reliable than the alternate two-step GMM estimator (Bond, 2002).

[20]This transformation is expressed as $y^*_{it} = c_{it}(y_{it} - \frac{1}{T_{it}} \sum_{s>t} y_{is})$.

Table 4: First Glance Panel Results

Equation	(1) Pooled OLS Levels	(2) Fixed Effects Levels	(3) 2SLS Difference	(4) 1-step GMM Difference	(5) 2-step GMM Difference	(6) 2-step GMM Orthogonal
Lag Inf	0.803***	0.704***	1.365***	0.743***	0.743***	0.735***
	(0.03)	(0.02)	(0.07)	(0.04)	(0.04)	(0.04)
Dom Gap	0.369**	0.302**	0.475	0.383*	0.389*	0.325**
	(0.17)	(0.14)	(0.33)	(0.22)	(0.22)	(0.14)
For Gap	0.437	0.453*	0.474	0.549**	0.539*	0.449**
	(0.27)	(0.23)	(0.69)	(0.28)	(0.28)	(0.22)
Constant	1.433**	2.360***	-0.105	1.968***	1.912***	2.037***
	(0.60)	(0.23)	(0.18)	(0.67)	(0.65)	(0.69)
Observations	392	392	364	364	364	364
RMSE	10.99	10.71	18.31	13.53	13.53	11.11

Sample period 1970-2013. Standard errors robust to heteroskedasticty and clustered at country level in parentheses.
***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

4.3.3 Concerns with Dynamic Panel GMM Estimation

A number of recent studies, including Bazzi and Clemens, 2013, Roodman, 2009 and Bun and Windmeijer, 2010, have cast doubt on the dynamic panel GMM estimations that have been employed in prominent empirical applications. In particular, three key issues have been raised in regards to this estimation methodology:

1. The number of instruments used.
2. Potentially weak instruments.
3. Endogeneity concerns.

We address each of these issues as it relates to our own dynamic panel GMM estimates presented in Table 4 and show that our findings remain robust in these scenarios.

Since lags of the dependent variable are often used as instruments in the GMM estimation of dynamic panels, more and more lags become valid instruments as the time period increases. This proliferation of instruments, however, is not without costs as discussed in Roodman (2009). First, a large number of instruments can overfit the endogenous variables, leading to biased estimates in the second stage of the estimation (in theory, the more the instruments there are the closer we get to the original biased OLS estimates). A large number of instruments also weakens the Hansen test for instrument validity, so in extreme cases the null is never rejected (Bowsher, 2002). Given these concerns, we check the adequacy of our dynamic panel estimates by reducing the number of lags used as instruments in the GMM estimation. [21]

Table 5 reports the results of the two-step GMM estimation of the dynamic panel with the reduced instrument set. We start with the forward orthogonal transformation and in each time period, we use only the last two lags from the instrument set to give us a total of 28 instruments in the GMM estimation (excluding period dummies). Encouragingly the estimates are similar to those seen in Table 4, with both the domestic and foreign output gaps remaining significant at the 5% level. The next four columns look at the sensitivity of these estimates by changing the instrument set as we go from using only the most recent lag each time period (a total of 16 instruments), to collapsing the full instrument set (again 16 instruments), to collapsing the second-lag instrument set (corresponding to only two lags of inflation as instruments) to finally collapsing the first-lag instrument set (corresponding to the just identified case). We see that in all these cases the estimates for the domestic and foreign output gaps remain significant while the lagged inflation term continues to have

[21] See appendix 4.6.3 for details on the instrument sets made by these methods.

theoretically appropriate values. In the last three columns of Table 5, we estimate (2) with the first-differences transformation. We again see that the results from the reduced instruments are similar to the corresponding full-instrument estimates in Table 4.

With the reduced number of instruments we are also able to use the Hansen test of instrument validity with greater confidence. Based on the p-values we can not reject the null of valid instruments for most of the instrument sets in Table 5 (the sole exception is the one-lag instrument set). We also use the difference-in-Hansen test to look at the validity of a subset of the instrument variables (in our case these are the foreign and domestic output gaps which have been used to instrument themselves). The high p-values from these tests generally support treating these output gaps as exogenous.

Table 5: Dynamic Panel GMM Estimation (reduced instruments)

	Orthogonal					Difference		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IV Set ($\pi_{i,t-1}$)	*Second-lag*	*First-lag*	*Collapsed*	*Two Lags*	*One Lag*	*Second-lag*	*First-lag*	*Collapsed*
Lag Inf	0.763***	0.771***	0.856***	0.922***	0.889***	0.754***	0.755***	0.843*
	(0.06)	(0.06)	(0.05)	(0.07)	(0.05)	(0.08)	(0.10)	(0.03)
Dom Gap	0.334**	0.329**	0.316**	0.202**	0.399**	0.354	0.299 *	0.336
	(0.15)	(0.16)	(0.15)	(0.10)	(0.19)	(0.27)	(0.23)	(0.24)
For Gap	0.457**	0.431**	0.427**	0.652***	0.4730*	0.540**	0.850**	0.541*
	(0.23)	(0.21)	(0.19)	(0.20)	(0.25)	(0.31)	(0.39)	(0.38)
Constant	1.779**	1.417**	0.737	0.031	0.597	1.832*	1.577*	0.799
	(0.78)	(0.62)	(0.52)	(0.49)	(0.55)	(0.89)	(0.95)	(0.43)
Instruments	28	16	16	5	4	28	16	16
p-values								
AR(2) test	0.25	0.25	0.25	0.23	0.23	0.24	0.24	0.23
Hansen J-test	0.28	0.05	0.10	0.22	.	0.28	0.22	0.09
Diff-in-Hansen	0.71	0.46	0.20	.	.	0.88	0.54	0.21

***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

Even with valid instruments, the IV estimates from 2SLS or GMM can still be biased if there is weak correlation between the instruments and the endogenous variables. The bias of the IV estimator increases as the correlation weakens and approaches the initial biased OLS estimates (Stock et al., 2002). Furthermore, inference in the presence of weak instruments leads to misleading results, especially in tests of over-identifying restrictions (Hahn and Hausman, 2002).

It has thus become necessary to test the strength of the instruments used in the IV estimation. The Kleibergen and Paap (2006) LM test can be used to test the rank condition of the instruments and is also robust to non-i.i.d. errors. A rejection of the null then implies that the structural equation is properly identified. To test for weak instruments, Stock and Yogo (2005) have also proposed an F-statistic in the first-stage regressions that is based on the Cragg and Donald (1993) Wald statistic and is able to incorporate multiple endogenous variables. Notably, Stock and Yogo (2005) apply this F-statistic to construct critical values that can be used to identify instruments as weak for certain levels of relative bias and size distortions of the Wald test for parameter inference.[22]

Table 6 shows the weak instrument tests for the dynamic panel estimations that were reported in Table 5. We look at both the first-differences and orthogonal transformations along with the different instrument sets that have been used in Table 2 to reduce instrument proliferation.[23] Focusing first on the orthogonal transformations, we see that the Kleibergen-Paap LM test strongly rejects the null, so we can use each of these instrument set to identify the structural equation. The Cragg-Donald Wald statistic based on the first-stage regressions is also quite high for these instrument sets. We then compare this statistic with the

[22]These critical values depend on the type of IV estimator being used along with the number of endogenous variables and excluded instruments in the regression.

[23]When conducting the weak instrument tests for the orthogonal transformation case, all regressors in the 2SLS are orthogonally transformed and instrumented by the lagged levels analogous to the dynamic panel GMM estimation.

corresponding Stock and Yogo (2005) critical values and can see that the instruments are sufficiently strong such that the asymptotic relative bias of the 2SLS estimator is less than 10%, so making IV estimates based on these instruments reliable for inference. Table 6 also reports the Kleibergen-Paap Wald statistic which is a robust analog of the Cragg-Donanld statistic and allows for the possibility of non i.i.d. errors. Again we see quite high values for our instrument sets which indicate that weak instruments are not a problem in our IV estimation. Note that the Stock and Yogo (2005) critical values are only valid for the i.i.d. case and so caution should be exercised when using them with the Kleibergen-Paap Wald statistic (Baum et al., 2007). Finally we see similar results for the first-differences transformation, although the Cragg-Donald statistic are not as high as the corresponding orthogonal transformations, indicating that lagged levels are stronger instruments when the level equation undergoes an orthogonal transformation. So going forward we will rely on the orthogonal transformation for our dynamic panel GMM estimates.

Table 6: Weak Instruments in dynamic panel

	Orthogonal			Difference		
	(1)	(2)	(3)	(4)	(5)	(6)
IV Set ($\pi_{i,t-1}$)	*Second-lag*	*First-lag*	*Collapsed*	*Second-lag*	*First-lag*	*Collapsed*
Excluded Instruments	25	13	13	25	13	13
Kleibergen-Paap LM Stat	45.38	27.71	39.28	42.93	33.61	30.08
	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Cragg-Donald Wald Stat	96.73	160.23	103.73	19.60	29.85	12.23
Kleibergen-Paap Wald Stat	117.51	81.25	16.15	103.57	81.50	3.95
Stock-Yogo Critical values						
Relative bias > 10%	11.38	11.52	11.52	11.38	11.52	11.52
Size of 5% test >15%	38.77	24.42	24.42	38.77	24.42	24.42

These tests are conducted with 2SLS where the number of excluded instruments are the lags of inflation in the IV set. The null hypothesis of the Kleibergen-Paap LM test is that the structural equation is underindentified with the p-values in parenthesis. With only one engogenous variable, the Cragg-Donald Wald test is analagous to the standard first stage F-test (the Kleibergen-Paap Wald test extends it to the case of heteroskedastic disturbances).

The Hansen tests in Table 5 are generally supportive of the validity of the instruments used in the GMM estimation, including treating the output gaps as exogenous variables. However, as discussed in Martinez-Garcia and Wynne (2010), output gaps in practice are measured with considerable error since potential output is not directly observable, and further aggregate data from emerging economies, needed to construct foreign output gaps, is unreliable and often times incomplete. Given this bias from measurement error and the potential of past shocks to influence the output gaps, the exogenity of the output gaps may not hold in equation (2). So we next examine the robustness of our findings by changing the instruments used for the output gaps. More specifically, instead of treating both output gaps as strictly exogenous, we consider the scenario where the output gaps are treated as either predetermined variables ($E[Y_{is}\varepsilon_{it}] = 0$ for $s \geq t$) or as endogenous variables ($E[Y_{is}\varepsilon_{it}] = 0$ for $s > t$).[24] When the gaps are taken as predetermined then Y_{t-1} and earlier lags are valid instruments for $Y_t - Y_{t-1}$ in the differences equation (when gaps are taken as endogenous we use Y_{t-2} and earlier lags as valid instruments for $Y_t - Y_{t-1}$).

The results of these estimations based on the orthogonal transformations are reported in Table 7 with caution being exercised in regards to the number of lags used as instruments. To be consistent we use the same instrument set for the lagged inflation term (Two Lags (collapsed) set in Table 5) and vary only the lags used as instruments for the output gaps. In the first three columns of Table 7 the output gaps are taken as predetermined, and we see similar estimates as the instrument set for the output gaps is reduced. In all three columns, both gaps are significant and similar in size to those found in Table 5. Further, the Hansen test is unable to reject the validity of these lags of output gaps as instruments in these estimations. In the last three columns of Table 7 we treat the gaps as endogenous and continue to see significant output gap estimates.

[24]Note that both predetermined and endogenous variables allow past shocks to influence the current values.

Table 7: Controlling for Potential Endogeneity

	Predetermined			Endogenous		
	(1)	(2)	(3)	(4)	(5)	(6)
IV Set ($Y_{i,t}$)	*Collapsed*	*Two lags*	*One Lag*	*Collapsed*	*Two lags*	*One Lag*
Lag Inf	0.857***	0.881***	0.923***	0.852***	0.853***	0.929***
	(0.05)	(0.05)	(0.07)	(0.05)	(0.04)	(0.08)
Dom Gap	0.431**	0.312**	0.229**	0.423*	0.189	0.470
	(0.21)	(0.12)	(0.10)	(0.23)	(0.25)	(0.35)
For Gap	0.433*	0.408**	0.624***	0.605*	0.729*	0.161
	(0.24)	(0.20)	(0.20)	(0.32)	(0.42)	(0.34)
Total Instruments	31	7	5	29	7	5
Hansen J-Test	0.50	0.12	0.22	0.34	0.16	0.22

Gaps predetermined(endogenous) then Y_{t-1} (Y_{t-2}) and earlier are used in the instrument set.

4.3.4 Robustness Checks

We next look at the validity of our main findings by adding external trade controls to the inflation process as well as by restricting the sample to periods after 1984. We use the period-to-period change in the real exchange rate as the control for direct effects of trade on domestic prices. The real exchange rate is a suitable empirical proxy for the terms of trade which is often incorporated as a structural determinant of inflation in an open-economy Phillips Curve framework (Gali and Monacelli 2005). In this regard the real exchange rate is a better than import price indexes, which have also been used as controls in earlier studies.

By looking at the periods after 1984, we are also able to better account for the structural break in inflation that occurred for most advanced economics in this era (Rapach and Wohar, 2005). The significant decrease in inflation rates in the early 80s was often a result of more aggressive central bank actions, so it is inappropriate to link this decline solely with higher levels of globalization and trade openness (Calza, 2009). A further benefit is that by restricting the sample to 1984-2013 we are able to reduce the time dimension of our panel and, in doing so, are able to use annual data instead of three-year averages in our dynamic panel analysis. Our overall goal in this section is to see whether these changes impact the output gap responses, especially the significance of the foreign output gap that was found in the earlier dynamic panel estimations.

Table 8 gives the estimation results of the dynamic Phillips Curve with the trade control for the full sample period. We again look at different sets of instruments for the same specification to ensure that our findings are robust to choice of instrument set. In the first two columns, we see that the foreign output slopes remain significant but are slightly diminished in terms of magnitude from the estimates in Table 5. One aspect could be that the real exchange rate variable is now capturing some of the impact of globalization on inflation. Indeed, the real exchange rate term has a negative sign, which is appropriate since an increase in the real exchange rate should lead to lower inflation. Still Table 8 shows that the impact from changes in the real exchange rate is not strong enough to be a significant determinant in the inflation process. We also tested our model with just the real exchange rate term (excluding the foreign output gap term) in our specifications and find it to have little significance. In columns five and six we include trade openness as a direct determinant of inflation and see little change from the baseline results, with trade openness having a slight negative effect on inflation levels. Samimi et al. (2012), using a broad measure of globalization, have also found that inflation is lower in more open countries. As in IMF (2006), we also considered the interaction term of the foreign output gap and trade openness in these specifications but it was found to be insignificant. Overall, the results support the use of the foreign output gap as the best measure to capture the effects of external factors in the inflation process.

Table 8: Trade Controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IV Set ($\pi_{i,t-1}$)	*Collapsed*	*One Lag*	*Collapsed*	*One Lag*	*Collapsed*	*One Lag*	*Collapsed*	*One Lag*
Lag Inf	0.861***	0.894***	0.871***	0.900***	0.833***	0.859***	0.835***	0.864***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)
Dom Gap	0.363***	0.438**	0.389***	0.534***	0.331**	0.384**	0.396***	0.475***
	(0.13)	(0.20)	(0.10)	(0.17)	(0.15)	(0.18)	(0.12)	(0.15)
For Gap	0.369**	0.453*			0.399**	0.440*		
	(0.17)	(0.24)			(0.17)	(0.24)		
Real Exch	-0.204	-0.263	-0.215	-0.278				
	(0.22)	(0.26)	(0.20)	(0.26)				
Openness					-0.051	-0.068*	-0.049	-0.071*
					(0.03)	(0.03)	(0.03)	(0.03)
Instruments	17	5	16	4	17	5	16	4
p-values								
AR(2) Test	0.25	0.24	0.25	0.24	0.25	0.24	0.25	0.24
Hansen J-Test	0.11	.	0.47	.	0.60	.	0.28	.
Diff-in-Hansen	0.10	.	0.85	.	0.73	.	0.69	.

Notes: One Lag uses the collapsed first-lag only instrument set for π_{t-1}. See also Table 5

Table 9 gives the estimates of (2) for annual data from 1984-2013. We continue to observe that the foreign output gap is significant and has a bigger impact on inflation than the domestic output gap across the various specifications and instrument sets. In columns seven and eight, we further restrict our sample to the period 1984-1998 to exclude the effects of the common monetary framework that was adopted by some of the European Monetary Union countries in our panel (Grüner and Hefeker, 1999). The estimates for the foreign output gap remain significant and with similar magnitudes, so we can be reasonably confident that the increased impact of the foreign output gap on inflation dynamics is not an artifact of some of our panel countries having a single monetary regime in the latter years of the sample.

Table 9: Dynamic Panel GMM estimates (Annual data)

	(1)	(2)	(3)	(4)	(5)	(6)
IV Set ($\pi_{i,t-1}$)	*Collapsed*	*One lag*	*Collapsed*	*One lag*	*Collapsed*	*Two lag*
Lag Inf	0.934***	0.941***	0.942***	0.948***	0.811***	0.780***
	(0.10)	(0.11)	(0.10)	(0.11)	(0.19)	(0.18)
Dom Gap	0.047	0.056**	0.075*	0.083**	0.072**	0.088***
	(0.03)	(0.02)	(0.04)	(0.03)	(0.03)	(0.03)
For Gap	0.229***	0.261***	0.180***	0.214***	0.217***	0.282***
	(0.06)	(0.10)	(0.05)	(0.07)	(0.06)	(0.09)
Real Exch Rate			-0.082	-0.130	-0.054	-0.125
			(0.07)	(0.09)	(0.04)	(0.09)
Second Lag Inf					0.168*	0.198**
					(0.09)	(0.08)
Total Instruments	8.00	4.00	9.00	5.00	9.00	6.00
p-values						
AR(2)	0.70	0.65	0.73	0.89	0.14	0.07
Hansen J-Test	0.27	.	0.26	.	0.19	.

Sample period 1984-2013 with robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.4 Threshold Analysis

Using a dynamic panel framework, we have shown a clear role for globalization factors such as the foreign output gap in the standard Phillips Curve. We now turn our attention towards investigating whether there is a non-linear relationship between globalization and inflation. It seems rather intuitive that as a country becomes more open, it should also be more influenced by external factors. Ahmad and Civelli (2015), focusing at the individual level for a sample of OECD countries, have shown: 1) trade openness is an appropriate threshold variable for most nations' Phillips Curve; 2) the influence of the foreign output gap on inflation replaces that of the domestic gap after a country reaches a certain level of globalization. By examining the threshold effect in a panel setting, we are able to exploit not only the time variation in openness at the country level but also the substantial differences in openness across countries. Thus we should be able to get more robust estimates of the threshold in a panel framework. The estimated threshold for openness can then be used as a guide to identify the regions where foreign factors start to dominate domestic factors in determining a country's inflation level.

4.4.1 Methodology

We investigate potential non-linearity in the inflation globalization relationship using the following dynamic panel threshold Phillips Curve model:

$$\pi_{it} = \rho_i \pi_{i,t-1} + (\beta_1 Y_{it}^d + \gamma_1 Y_{it}^f) I(Open \leq \tau) + (\beta_2 Y_{it}^d + \gamma_2 Y_{it}^f) I(Open > \tau) + \eta_i + \varepsilon_{it} \qquad (3)$$

where trade openness acts as the threshold variable in the relationship between inflation and the output gaps and causes the switch from one regime to another. Trade openness is a popular proxy for a country's level of globalization and is especially relevant because inflation in an open-economy Phillips Curve is affected by external factors primarily through the trade channel. Model (3) allows openness to influence only the slopes of the gaps, while the persistence given by the lagged inflation terms is the same for each regime. Bick (2010) has shown that regime intercepts can often play a significant role in a panel threshold analysis. Thus for robustness we estimate equation (3) with and without a regime-specific intercept term. Overall this threshold model incorporates potential non-linearity in a simple manner such that the foreign output gap impacts inflation only after a country achieves a certain degree of openness.

Hansen (1999) has developed an asymptotic theory that can be used for both estimating and testing non-dynamic panel threshold models. The key is to eliminate first the fixed effects using the standard within-mean transformation and then, as in the cross-sectional framework (Hansen, 2000), the consistent estimate for the threshold is the one that minimizes the residual variance of the regression. The standard approach is to use a grid search over all the values of the threshold variable and then, conditional on this threshold value, estimate the remaining variables in each regime by least squares. An F-test or the heterscedasticity-consistent Wald Test can be used to determine if the slopes in the two regimes are significantly different from one another and thus the overall appropriateness of the non-linear model.[25] However, the distribution of these test statistics is non-standard, so Hansen (1999) suggests using a bootstrap approach to approximate the asymptotic null distribution of the test statistic.

The above approach is valid only when all the explanatory variables in the model are strictly exogenous. Caner and Hansen (2004) extend the threshold model to account for the possibility of endogenous regressors by performing the threshold estimation in three stages. First, they regress the endogenous variables on the instruments along with the other exogenous explanatory variables in the model. They then use these predicted values of the endogenous variables instead of the actual values in the grid search for finding the threshold estimate. Lastly, the estimated threshold is used to split the sample and a 2SLS or GMM estimator is used to get the coefficient estimates in each regime.

The endogenous threshold framework in Caner and Hansen (2004) can be adapted to the

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[25]The Wald Statistic is calculated as $W_T(\gamma) = \left[\hat{\theta}_1(\gamma) - \hat{\theta}_2(\gamma)\right]' \left[\hat{V}_1(\gamma) - \hat{V}_2(\gamma)\right]^{-1} \left[\hat{\theta}_1(\gamma) - \hat{\theta}_2(\gamma)\right]$ where for a given value of γ in the grid search, $\hat{\theta}_1$, $\hat{\theta}_2$ are the slope estimates and $\hat{V}_1$,$\hat{V}_2$ the estimated covariance matrices in each regime. The maximum W_T from the grid search is then be used to test $H_0 : \theta_1 = \theta_2$.

non-dynamic panel case by simply removing the individual-specific fixed effects and then proceeding as before. However, with dynamic panels the within-mean transformation cannot be used to eliminate η_i because it leads to inconsistent estimates due to the correlation between the transformed dependent variables and the error term. The first-differences transformation is also not appropriate as it causes the transformed error terms to become serially correlated.[26] On the other hand, the forward orthogonal transformation is able to remove η_i while also preserving the original error structure and so maintains the serial independence of the transformed error term (Arellano and Bover, 1995). Kremer et al. (2013) were the first to make use of this approach, showing with a Monte Carlo study that it led to significant improvement in the estimation of dynamic panel threshold models. [27]

We follow a similar methodology in estimating the dynamic panel threshold model given in (3). We first use a forward orthogonal transformation on all the variables except the threshold variable and the instruments (the lagged inflation terms). We then regress the transformed endogenous variable π^*_{t-1} on the selected instrument set, and their predicted values are then used in the grid search procedure. We conduct the grid search on the sorted values of the threshold variable, which have been trimmed 15% on each side to ensure enough observations in each regime. Using the consistent threshold estimate, we estimate model (3) with GMM to obtain the coefficients in each regime (for the GMM estimation we employ the same robust weighting matrix that was used in the dynamic panel analysis with all the standard errors adjusted using the Windmeijer (2005) correction). Finally we employ a bootstrap procedure, as described in Caner and Hansen (2004), to test the statistical significance of the threshold in our model.

[26] An independent error term is a key requirement for the asymptotic distribution theory in Hansen (1999).

[27] This methodology has been also used to investigate the non-linear impact on economic growth from public debt (Baum et al., 2013) as well as from financial development (Law and Singh, 2014).

4.4.2 Threshold Estimates

Table 10 gives the results of the dynamic panel threshold estimation. As in the dynamic panel analysis, having a large set of instruments can potentially bias the estimates of the threshold model. Thus we remain conservative in the choice of the lagged inflation terms used in the instrument set, restricting them to the collapsed, two lags only and one lag only options. Focusing on the model with a regime-specific constant, we see that the estimated threshold τ is around 52% which splits the sample into 246 observations in the closed regime and 146 observations in the open regime (so more observations classified closed than open for this threshold estimate). The 90% Confidence Interval (CI) for τ is given by [35, 57] and notably this CI is also robust across the different instrument sets used in Table 10. Further, the bootstrapped p-values for the Wald test easily reject the null of no threshold for this model, and so we can conclude that trade openness does indeed have some non-linear effects on a country's inflation dynamics.

If the inflation globalization hypothesis is valid, then we would expect the following:

1. In the more open regime, the response of inflation to the domestic output gap, β should decline and become less significant.
2. In the more open regime, the foreign output gap should replace the domestic output gap, indicating a more significant and larger estimate of γ.

Examining Table 10 and focusing on the collapsed instrument set in the first column, we see that in the less open regime the domestic output gap is highly significant while the foreign output is insignificant and does not play an important role in the inflation process. However, in the more open regime we see a clear shift in the output gap slopes with the foreign output

Table 10: Dynamic Panel Threshold estimates

		(1)	(2)	(3)
	IV Set ($\pi_{i,t-1}$)	*Collapsed*	*Two Lags*	*One Lag*
	Threshold	51.79	51.93	51.93
	90% CI	[35.44, 57.05]	[35.44, 57.05]	[35.44, 57.05]
	Lag Inf	0.8637***	0.8472***	0.8957***
		(0.05)	(0.23)	(0.20)
Open≤ τ	Constant	0.8977	0.0674	0.0337
(246 obs)		(0.71)	(2.26)	(1.87)
	Dom Gap	0.4948***	0.4878**	0.6831***
		(0.20)	(0.24)	(0.27)
	For Gap	0.3409	0.5621	0.3084
		(0.26)	(0.37)	(0.41)
Open≤ τ	Dom Gap	0.0642	0.0605	0.0541
(146 obs)		(0.10)	(0.14)	(0.14)
	For Gap	0.6873**	0.8822**	0.8987***
		(0.32)	(0.38)	(0.36)
	Instruments	18	7	6
	Hansen J-test	0.14	0.22	.
	Wald Stat	4.14	7.90	8.97
	Bootstrap p-value	0.10	0.08	0.04

Threshold was estimated such that each regime has 15% of the observations.
***, **,* indicate significance at the 0.10, 0.05 and 0.01 level respectively.

gap slope now significant and having a larger magnitude than the domestic output gap slope. Based on this result, we can determine that the foreign output gap replaces the domestic output gap as the key determinant of inflation in the more open regime. Note that Table 10 also shows that this trend is consistent across the different instrument sets. In particular, with only the last inflation lag as an instrument, the model is just identified and so this shift in inflation dynamics is even robust to the particular weighting matrix employed in the

GMM estimation. Overall, these are strong findings in support of the view that external factors matter in the inflation process once a sufficient level of openness is reached.

We next look at the usefulness of our panel threshold estimates of trade openness and in particular the lower bound of the estimated CI, in determining if a given country is integrated with the global economy. In Ahmad and Civelli (2015), the median threshold for the countries, that had a significant non-linear effect on inflation from openness, was found to be about 45%, which is relatively similar to the panel threshold estimate of 51%. Figure 3 plots the country-specific thresholds from Ahmad and Civelli (2015), and we see that most of them fall within the 90% CI of the trade openness threshold found from the panel estimations. These individual threshold estimations were done on quarterly data for the sample period 1985-2006 using a backward-looking open-economy Phillips Curve model. This is encouraging as it provides support for the panel threshold analysis and suggests that the $[35 - 57]$ range for trade openness can be used by countries as a guide to determine if they should start to concentrate on external forces when formulating inflation policies.

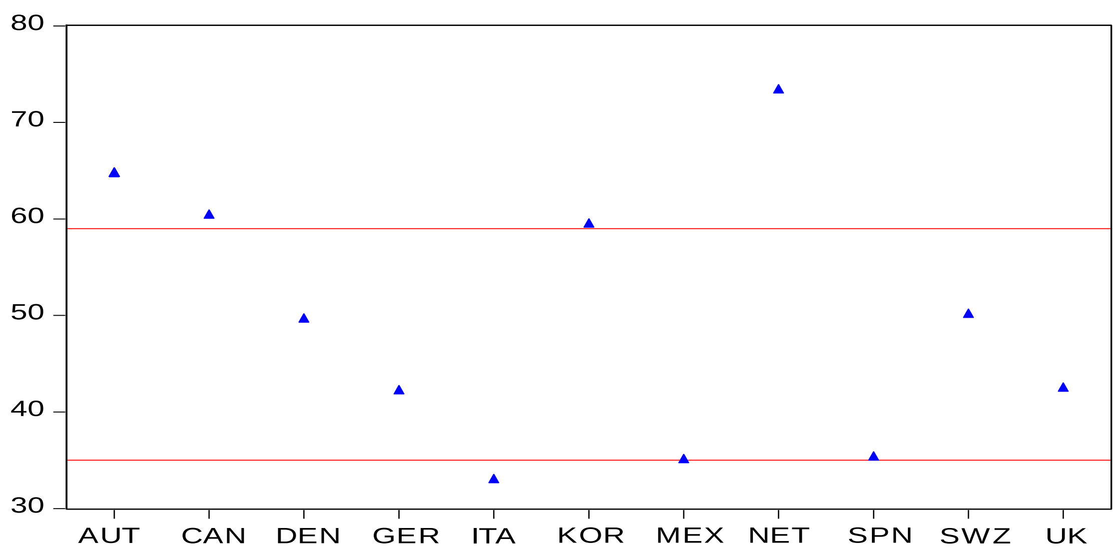

Figure 3: Individual and Panel Threshold Estimates of the OECD countries (1970-2013)

4.5 Conclusion

There are strong implications for monetary policy if inflation is indeed influenced more by global conditions, rather than domestic ones. For one, a diminishing response to domestic factors makes it more costly to stabilize inflation through standard policy actions (Calza, 2009). Alternatively, policy makers may feel that increased competition due globalization adequately anchors inflationary tendencies, and so are able to concentrate more on increasing domestic output levels (López-Villavicencio and Saglio, 2014). Given these important policy consequences, it is imperative to identify the exact role globalization plays in the inflation process.

Our paper makes a significant contribution by finding strong evidence in favor of including the global slack as a determinant in a country's domestic inflation process. We first show that cross-sectional variation in openness can be effectively used in a dynamic panel Phillips Curve model to identify the impact of foreign influence, represented by the foreign output gap, on domestic inflation levels. In contrast to previous empirical literature that looks at this relationship at the individual-country level, the larger cross-sectional differences in openness provide more suitable conditions to detect the potential effects of globalization. This result is also robust to the instrument proliferation and weak instrument problems that are often associated with the dynamic panel GMM methodology.

We then extend our modeling framework so that openness can have a non-linear role in the inflation process. Applying the dynamic panel threshold methodology, given in Kremer et al. (2013), we show that trade openness is an appropriate threshold variable and leads to an economically meaningful change in a country's inflation dynamics. Our estimates of the panel threshold model are also consistent with the inflation globalization hypothesis, with the foreign output gap replacing the domestic output gap as the driver of domestic inflation in the more open regime. So our threshold approach also provides a suitable tool to inform the policy making process with respect to the influence of relevant external forces.

In our analysis, we have utilized a country's level of trade openness to capture its degree of integration in the global markets. However, globalization is a complex phenomenon that can be measured across various economic, social and political dimensions (Dreher et al., 2008). It would be interesting to examine if other economic measures of globalization such as integration in financial markets and labor mobility can also have non-linear effects on the inflation process. A further possibility is to treat this non-linearity as a Markov-Switching Process (Hamilton, 1989), which can then be incorporated in a DSGE model (Farmer et al., 2009) to better understand the structural underpinnings of this relationship. For as we have shown, non-linearity needs to be explicitly modeled and included in the analysis of the inflation globalization hypothesis.

4.6 Appendix

4.6.1 Dataset

In our panel data we analyze the following twenty eight OECD countries: U.S., U.K., Germany, France, Italy, Spain, Ireland, Denmark, Netherlands, Austria, Switzerland, Canada, Mexico, Australia, Japan, South Korea, Belgium, Luxembourg, Norway, Sweden, Finland, Greece, Iceland, Portugal, Turkey, Hungary, Israel and New Zealand. In addition to these countries, an additional seventy countries were also included for the construction of the trade weights.[28] We next provide details of this dataset and the construction of the trade-weights.

The main sources are the OECD database (STAT), the IMF's Direction of Trade (DOT) and International Financial Statistics (IFS) and Penn World Table Version 8.0 (PWT).

Trade Flows: DOT provides the pairwise trade flows among all the countries in our sample universe. The flows are measured in current U.S. dollars for all countries. DOT treats Belgium and Luxembourg as separate countries only after 1997 and Germany is defined as West Germany alone before the 1991 reunification. Uruguay is excluded due to missing observations.

Trade Openness: Exports, Imports and GDP (all in nominal terms) are obtained from STAT to calculate this measure for the countries in our sample. Due to missing observations, PWT (openc) was used for Hungary, Israel, Luxembourg and Mexico.

Real GDP: STAT and PWT are used to get the real output values. To improve data quality, we use historical data from Maddison (1995) for Yugoslavia, USSR, and Czechoslovakia. The output gap is then constructed as $gap_{i,t} = \frac{gdp_{i,t}}{pot_{i,t}}$-1 where the Potential GDP is obtained from

[28]These countries were chosen based on their economic size.

using an HP filter on the real GDP series. This measure for the output gap is similar to the one used by the OECD's Economic Outlook. To avoid end-of-sample issues with the HP filter, the Real GDP for each country was forecasted five years ahead using an AR(2) model.

Nominal Exchange Rates: We use the U.S. dollar as pivotal currency for the bilateral exchange rates between the U.S. and the other countries in the sample; this allows the creation of a pair-wise dataset for each country.

Trade weights for imports, exports and third party ($w^m, w^x$and w^p) are determined as:

$$w^m_{i,j,t} = \frac{M_{i,j,t}}{\sum_{j=1}^{N_t} M_{i,j,t}} \tag{4}$$

$$w^x_{i,j,t} = \frac{EX_{i,j,t}}{\sum_{j=1}^{N_t} EX_{i,j,t}} \tag{5}$$

$$w^p_{i,j,t} = \sum_{k \neq j \neq i}^{N_t} w^x_{i,k,t} \frac{w^m_{k,j,t}}{1 - w^m_{k,i,t}} \tag{6}$$

where $M_{i,j}$and $EX_{i,j}$ indicate imports from country j to i and exports from i to j. Weights are then aggregated as

$$w_{i,j,t} = 0.5w^m_{i,j,t} + 0.5(0.5w^x_{i,j,t} + 0.5w^p_{i,j,t}) \tag{7}$$

The foreign output gap for country i is then the weighted average, using the weights in (7), of the domestic output gap for all the other countries in the sample universe. Similarly the real exchange rate index I_t for country i, using these same weights, is the geometrically weighted average of the bilateral exchange rates.

4.6.2 Bias-corrected Fixed Effects Estimation

In our analysis of the inflation globalization hypothesis, we have relied on the Arellano and Bond (1991) GMM methodology to account for the fixed effects term η_i and get consistent estimates of the dynamic panel model. One reason for this choice, is that in a dynamic panel framework the traditional Fixed Effects (within mean) estimator is biased for finite T (Nickell, 1981). However, for large T, it is still consistent, so an alternate approach in estimating dynamic panel models is to use the Fixed Effects estimator with an approximation made to correct for the small sample bias. In a Monte Carlo study, Judson and Owen (1999) have shown that for macro panels, where N is typically small, the bias-corrected Fixed Effects estimator is more accurate and with a smaller variance than the GMM estimators. Thus in this section we estimate (2) using annual data (so large T) with the bias-corrected Fixed Effects estimator and examine whether this impacts our main findings.

Kiviet(1995; 1999) has developed higher-order asymptotic expansion techniques to approximate the small-sample bias of the Fixed Effects estimator up to an accuracy of order T^{-1}, $N^{-1}T^{-1}$ and $N^{-1}T^{-2}$ respectively. In order to calculate the bias terms in practice, a consistent estimator is first needed to get estimates for the lagged term and the residual variance. Kiviet (1995) suggests using 2SLS, as in Anderson and Hsiao (1981), or GMM, as in Arellano and Bond (1991), to get these estimates and then plug them in the desired bias-approximation formula. The bias-corrected Fixed Effects estimates (FE^c) are then obtained by just subtracting these bias approximations from the original Fixed Effects coefficients.

Table 11 reports the panel estimates for the whole sample period (1970-2013) and sub-sample period (1984-2013) using annual data. We first examine the standard Pooled OLS and Fixed Effects estimates which show significant coefficients for both the domestic and foreign output gaps. Since these estimates are biased due to the presence of the lagged dependent variable, we next turn to the bias-corrected Fixed Effects estimates. We use both the AH(Anderson and Hsiao, 1981) and the AB(Arellano and Bond, 1991) estimators to initialize the bias correction terms and see similar coefficient estimates for the two output gaps in columns three and four. The estimated coefficients in these two columns have an approximation error of order $O(N^{-1}T^{-1})$. In both cases, the foreign output gap is significant while the domestic output gap is of smaller magnitude and not significant at the 10% level. As in Bun and Kiviet (2001), a parametric bootstrap procedure has been applied to get the estimated standard errors for these bias-corrected Fixed Effects estimators. Overall we continue to find significance of the foreign output gap in our panel analysis despite relying on a different empirical methodology, which increases the robustness of our results in Section 4. Finally, a Mean Group estimator, as proposed in Pesaran and Smith (1995), is also used to allow for heterogeneous slope coefficients in (2) and we see little change in the significance of these two output gaps in the inflation process.

Table 11: Fixed Effect Results (Annual Data)

Period: 1970-2013

	(1) POLS	(2) FE	(3) $FE^c(AH)$	(4) $FE^c(AB)$	(5) MG
Lag Inf	0.851^{***}	0.766^{***}	0.766^{***}	0.817^{***}	0.769^{***}
	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)
Dom Gap	0.100^{**}	0.079^{**}	0.078	0.084	0.066^{***}
	(0.03)	(0.03)	(0.09)	(0.08)	(0.02)
For Gap	0.375^{***}	0.315^{***}	0.329^{**}	0.279^{**}	0.359^{***}
	(0.09)	(0.09)	(0.15)	(0.13)	(0.11)
RMSE	11.52	11.26	17.69	11.50	11.16

***, **,* significant at the 0.10, 0.05 and 0.01 level respectively.

4.6.3 Reducing Instrument Count

A standard way to represent the instrument matrix Z_i of $(\pi_{i,t-1} - \pi_{i,t-2})$ in the GMM estimation of (2) is as:

$$\begin{bmatrix} \pi_{i1} & 0 & 0 & 0 & \dots & 0 \\ 0 & \pi_{i2} & \pi_{i1} & 0 & \dots & 0 \\ . & . & . & & & . \\ . & . & . & & & . \\ 0 & 0 & 0 & 0 & \dots & \pi_{i,T-2} \end{bmatrix} \tag{8}$$

so Z_i corresponds to the $\frac{(T-2)(T-1)}{2}$ moment conditions $E[\pi_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$ for $t \geq 3,\ s \geq 2$. We then employ two ways to reduce the number of instruments given in (8).

One approach is to cap the number of instruments per periods by using the previous k lags only. Then the instrument count becomes linear in T (for example if $k = 1$ then only the most recent lag is used as instrument in each time period). We can then express Z_i^l as:

$$\begin{bmatrix} \pi_{i1} & 0 & 0 & 0 & \dots & 0 \\ 0 & \pi_{i2} & 0 & 0 & \dots & 0 \\ . & . & \pi_{i3} & & & . \\ . & . & . & & & . \\ 0 & 0 & 0 & 0 & \dots & \pi_{i,T-2} \end{bmatrix} \tag{9}$$

Another approach proposed by Roodman (2009) is to collapse the instruments in (8) so that one column is made for each lag distance (with zeros substituted for missing values).[29] A potential advantage of this approach is that no lags are actually dropped and so are able to retain more information. Z_i^c is then given as:

$$\begin{bmatrix} \pi_{i1} & 0 & 0 & 0 & ... & 0 \\ \pi_{i2} & \pi_{i1} & 0 & 0 & ... & 0 \\ \pi_{i3} & \pi_{i2} & \pi_{i1} & & & . \\ . & . & . & & & . \\ \pi_{i,T-2} & \pi_{i,T-1} & \pi_{i.T-3} & 0 & ... & \pi_{i1} \end{bmatrix} \tag{10}$$

Finally these two methods can also be combined to further reduce the number of instruments, so that collapsing the one lag only instrument set gives us the exact instrument $\pi_{i,t-2}$ that was used in Anderson and Hsiao (1981) :

$$\begin{bmatrix} \pi_{i1} \\ \pi_{i2} \\ \pi_{i3} \\ . \\ \pi_{i.T-2} \end{bmatrix} \tag{11}$$

[29]Roodman (2009) showed this imposes the moment condition $E[\pi_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$ for each $s \geq 2$.

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5 Conclusion

This dissertation examines potential nonlinearity in the response of monetary policy makers as well as between inflation dyanamics and global economic forces. In both cases we have found that allowing for nonlinear dynamics gives us a more complete picture of the underlying economic process.

Our results show that there is significant nonlinearity in the Fed's response reflecting asymmetric preferences toward both the output gap and inflation. Notably the responses in some of these regimes do not fall under a Taylor rule, suggesting that while the Fed prefers a systematic approach to monetary policy it also employs considerable discretion in trying to achieve key policy objectives. Our model is also able to provide insight on the Fed's response during the most recent financial crisis.

In the analysis of the inflation globalization hypothesis, we find evidence that trade openness is not rejected as threshold variable for the Phillips Curve model for most of the countries in our sample, and this non-linear component must be explicitly modeled. We find that as countries reach a certain level of openness, their domestic inflation starts to respond to external influences as captured by the foreign output gap. Accounting for non-linearities in the Phillips Curve reveals new evidence that contrary to the previous literature, which often ignores these effects, helps to corroborate the inflation globalization hypothesis. These results also hold in the panel threshold framework, with the foreign output gap replacing the domestic output gap as the driver of domestic inflation in the more open regime.