The Great Globalization and Changing Inflation Dynamics*

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This paper investigates the changing impact of economic globalization on U.S. inflation dynamics during the period from 1980 to 2012. We develop an extended New Keynesian Phillips curve incorporating richer dynamics and foreign economic slack from microfoundations. Using unknown structural break tests, we identify a significant structural change in the early 1990s in the model, after which domestic inflation responds more strikingly to the foreign than to the domestic output gap. The finding indicates that it is plausible for the Federal Reserve to augment its policy analysis framework with globalization factors in the globalized world.

JEL Codes: E31, E37, E52, E58, C22.

1. Introduction

The United States is quite an open economy today, and its trading partners' economic performance plays an important role in the slowly solidifying recent cyclical recovery. The rising economic globalization also brings an increasingly complex set of policy challenges. One of the leading challenges is the changing nature of inflation dynamics in the process of the current great globalization.[1] The past

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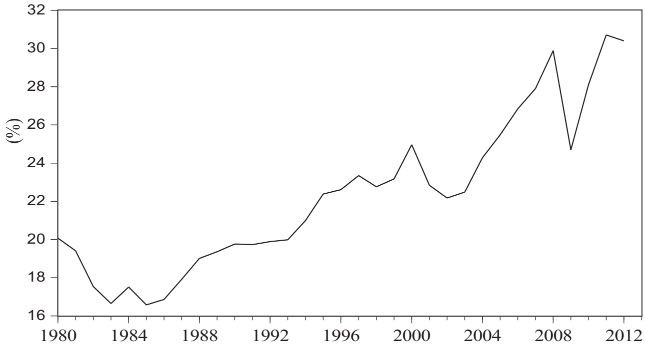
[1]The current age of globalization is regarded as the second great wave of globalization of international trade (and capital flows). The first wave of globalization occurred from the mid-1850s to the First World War; see O'Rourke and Williamson (1999) and Mishkin (2006) for the insight analyses of the first and the second waves of the great globalization, respectively.

Figure 1. U.S. Economic Globalization (exports plus imports of goods and services, % of GDP): 1980–2012



Source: U.S. Department of Commerce: Bureau of Economic Analysis, and the author's calculations.

decades saw a marked fall in U.S. inflation, also associated with a distinct increase in economic globalization. As figure 1 attests, the level of economic globalization in the United States, measured by total trade as percentage of nominal gross domestic product (GDP), has become increasingly more open over the past three decades, at a pace that has further intensified since the mid-1990s. The rising globalization potentially brings a new challenge for monetary authority: the central bank could cost the nation a dangerous lurch into secular deflation or unexpected high inflation if they fail to grasp profound global changes at play and their implications for domestic inflation developments.

This concern has ignited a growing number of studies investigating the effects of globalization on inflation, but the conclusions remain very different. The subject of the active debate in the literature is whether globalization has reduced the sensitivity of inflation to domestic economic slack while increasing the response of inflation to foreign economic slack. One branch of the literature believes that globalization has indeed led to a decline in the sensitivity of inflation to domestic factors. They argue that the integration of China and other lower-cost producers in world production networks increases competition and induces downward pressure on wages and import prices in industrial countries, which in turn remarkably subdues domestic inflation despite notable rises in commodity prices and a broadly accommodating monetary policy stance across the major currency areas. Gamber and Hung (2001), International Monetary Fund (2006), Pain, Koske, and Sollie (2006), Borio and Filardo (2007), Pehnelt (2007), Auer, Degen, and Fischer (2010), and Guerrieri, Gust, and López-Salido (2010) appear to support this argument.

In contrast, the empirical results for the euro area in Calza (2008), for Organization for Economic Cooperation and Development (OECD) economies in Ihrig et al. (2010), for the United States in Milani (2012), and for France, the United Kingdom, and the United States in Lopez-Villavicencio and Saglio (2014) show that globalization has little impact on the inflation process in major industrial countries. Still, other studies offer alternative explanations for the changing inflation performance in the industrial countries, including improved cyclical conditions (Buiter 2000), systematic improvements in monetary policy (Ball and Moffitt 2001; Kamin, Marazzi, and Schindler 2004; Roberts 2006; Mishkin 2007), or simply good luck (Stock and Watson 2007).

These conflicting findings may reflect the fact that the integration of emerging countries into the global economy can bring interconnecting and two-way impacts on the inflation process. On the one hand, higher demand may drive up prices for energy, raw materials, and general commodities, which will eventually reflect in overall price inflation. On the other hand, an influx of lower-cost labor, products, and services into the world market can also drive prices downwards. This two-way impact may also explain why the globalization–inflation relationship remains a "puzzle" (Temple 2002) when different pools of countries are considered as in Romer (1993) and Gruben and McLeod (2004).

The discrepancy in the literature also reflects the importance of reasonable model specification used in analyzing the globalization–inflation connection. For example, Borio and Filardo (2007) specify a stylized Phillips curve with lagged real domestic and foreign output gaps and find that the globalization factor (captured by foreign output gap) is a key determinant of domestic inflation. Instead of using lagged output gaps, Ihrig et al. (2010) modify Borio and Filardo's model specification by using contemporaneous output gaps (and making changes in the country weights, among other things), and the results appear to change dramatically. Ball (2006) and Mishkin

(2009), citing the empirical results in Ihrig et al. (2010), argue that there is little reason to think that globalization has changed the structure of inflation dynamics. In addition, the simulation results of the theoretical experiments based on a three-equation model of monetary transmission mechanism in Woodford (2009) also show that globalization does not weaken the ability of national central banks to control the dynamics of inflation.

The aforementioned studies provide useful contributions to the understanding of inflation dynamics in a globalized world. Two important issues, however, are underexamined in the literature. The first is the structural specification of an inflation dynamics model with globalization factors. The commonly used framework in the literature of globalization and inflation is a reduced-form model of a traditional backward-looking Phillips curve (e.g., Borio and Filardo 2007; Ihrig et al. 2010), which maintains the virtue of simplicity but neglects important microfoundations of the staggered-price-setting mechanism. According to modern monetary theory, estimated reduced-form inflation equations provide very little information regarding the role of global factors as determinants of inflation (Galí 2010). The backward-looking Phillips-curve framework also brings arbitrariness in detailed model specifications, which leads to difficulties in discriminating different results in the relevant studies.

The structural monetary models of an open economy developed in the seminal works of Clarida, Galí, and Gertler (2002), Woodford (2003), and Galí and Monacelli (2005) provide an important benchmark for structural modeling of inflation dynamics. Milani (2010, 2012) estimates the structural New Keynesian models to test whether globalization has changed the behavior of inflation dynamics in the United States and other G-7 economies. These structural models, however, emphasize the pure forward-looking behavior of inflation, which may not be able to capture the observed inflation inertia in the United States (and many other countries). Even though there are some studies that estimate hybrid New Keynesian Phillips-curve models with both forward- and backward-looking components, the backward-looking behavior is only captured by a stylized one lag. In this paper, we will extend the recent pricing behavior of the backward-looking firms to incorporate a weighted process of past inflation instead of a stylized one lag. We will also show that an extended model with both forward- and backward-looking inflation components and a foreign economic slack can be rationalized with a slight modification in a similar microeconomic framework to the literature.

A second, equally important but underexamined issue is potential structural changes in the impact of globalization on inflation dynamics. Over the long span of the past three decades in the United States, for example, the level of economic globalization has changed (increased) and hence the machinery of its economic interaction with the world economy may have experienced considerable changes. The rising globalization may make domestic inflation more responsive to foreign than to domestic economic slack via different channels. In a globalized world, foreign goods and services provide alternative choices for domestic consumers, so there will be less pressure for domestic prices to rise (Mishkin 2009). Rising globalization may also make the domestic firms more sensitive now than before to foreign economic performance in their price-setting process so that global factors will eventually have an impact on domestic inflation. Through either channel, the impact of globalization on domestic inflation may change over time. Borio and Filardo (2007) have noticed a possible impact of structural breaks on the effect of globalization inflation, but their analysis is largely based on informal break tests. Therefore, formal structural break tests are warranted in the relevant studies.

This paper attempts to fill the above two voids and focuses on the changing impact of globalization on inflation dynamics in the United States, linking the results to broader debates in the academic literature as well as policy implications. To this end, we develop an extended New Keynesian Phillips curve (NKPC) from an open-economy version of an extended Calvo's (1983) sticky price model with microeconomic foundations relating to the dynamic stochastic general equilibrium model. The extended NKPC incorporates both inflation expectations and inflation inertia, and includes foreign economic slack to provide a channel through which globalization may alter the dynamic response of inflation to domestic excess demand. Based on this model, we carry out unknown structural break tests over the period of 1980 to 2012 and find a significant structural break in the U.S. inflation dynamics in the early 1990s, after which an increase in globalization generates a larger increase in the response of inflation to the foreign than the domestic output gap.

The rest of the paper is organized as follows: Section 2 presents the baseline model and describes its connection with the microfoundation of sticky prices (with detailed model development presented in the appendix); section 3 describes the data used in empirical work and some stylized facts of globalization and inflation in the United States; section 4 discusses the econometric issues related to the empirical estimations and provides empirical results of the underlying model, followed by relevant implications explored in section 5; section 6 concludes the paper.

2. The Model

In this section, we construct a dynamic, microfounded inflation dynamics model for an open economy with sticky prices. Our model is a small but presumably important extension of recent developments in the open-economy dynamic stochastic general equilibrium (DSGE) literature pioneered by Obstfeld and Rogoff (1995, 2000), Clarida, Galí, and Gertler (2002), Smets and Wouters (2002), and Galí and Monacelli (2005). The households' consumption and savings decisions are in the spirit of Galí and Monacelli (2005), in which a representative household seeks to maximize a utility function with a composite consumption composed of both domestic goods and imported goods.

For the domestic monopolistically competitive goods market, we lay out an extended framework of Calvo (1983) that can be easily rationalized in terms of sticky price setting of backward-looking firms in the closed-economy models. In particular, for the pricing behavior of the domestic firms, we assume an economic environment similar to Calvo's (1983) model, in which firms are able to revise their prices in any given period with a fixed probability $(1 - \theta)$. In addition, we assume both "forward-" and "backward-looking" firms coexist in the economy with a proportion of ω and $(1 - \omega)$, respectively. Further, we extend the rule of the recent pricing behavior of the backward-looking firms to incorporate a weighted process of past inflation, instead of stylized one lag of inflation inertia.

Specifically, based on the regular assumptions in Calvo's model and log-linear approximations, it is possible to obtain the (log) aggregate price level by

$$p_t = \theta p_{t-1} + (1-\theta)p_t^{new}, \tag{1}$$

where p_t^{new} is the new price set in period t. Let p_t^f be the price set by forward-looking firms and p_t^b be the price set by backward-looking firms at time t. The new price (relative to the aggregate price) can be expressed as a convex combination of p_t^f and p_t^b, viz.

$$p_t^{new} - p_t = \omega(p_t^f - p_t) + (1-\omega)(p_t^b - p_t). \tag{2}$$

Next, following Woodford (2003), the pricing behavior of the forward-looking firms can be written as

$$p_t^f - p_t = \theta\varsigma \sum_{s=0}^{\infty} (\theta\varsigma)^s E_t\pi_{t+s+1} + (1-\theta\varsigma)\sum_{s=0}^{\infty}(\theta\varsigma)^s E_t mc_{t+s}, \tag{3}$$

where ς denotes a subjective discount factor, π_t denotes inflation rate, and mc_t is the real marginal cost of a typical domestic firm producing differentiated goods with a linear technology. Iterating (3) gives

$$p_t^f - p_t = \theta\varsigma E_t\pi_{t+1} + (1-\theta\varsigma)mc_t + \theta\varsigma E_t(p_{t+1}^f - p_{t+1}). \tag{4}$$

Assume a rule of thumb in the pricing setting, viz.

$$p_t^b - p_t = p_{t-1}^{new} - p_t + \pi_{t-1}. \tag{5}$$

As emphasized in the literature, this is an elegant innovation in that the backward-looking firms can now set their prices to the average price determined in the most recent price adjustments with a correction for inflation.

However, inflation inertia in (5) is confined to one single lag, which may neglect the importance of other historical inflation in predicting current inflation. In particular, if we interpret one period as being short, the backward-looking agents are likely to take more than one period to fully respond to changes in actual inflation. Therefore, it would appear reasonable to replace π_{t-1} in (5) with a weighted average of inflation over several periods in the past. Importantly, this replacement can effectively mitigate a serial correlation problem in empirical analysis. As such, we extend (5) in the following process:

$$p_t^b - p_t = (p_{t-1}^{new} - p_t) + \pi_{t-1} + \rho(L)\Delta\pi_{t-1}, \tag{6}$$

where $\rho(L) = \rho_1 + \rho_2 L + \cdots + \rho_m L^{m-1}$ is a polynomial in the lag operator. In practice, m may be specified by utilizing appropriate diagnostic tests (e.g., standard information criteria).

Combining (1)–(6), it can be shown that the dynamics of domestic inflation in terms of real marginal cost are described by an equation analogous to the one associated with a closed economy, viz.

$$\pi_t = \gamma_e E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \sum_{i=1}^{m-1} \alpha_i \Delta \pi_{t-i} + \lambda mc_t, \tag{7}$$

where coefficients of (7) are functions of the deeper parameters in (1)–(6).

As shown in the appendix of this paper, combining equation (7) with the equations depicting the representative household seeking to maximize a utility function with a composite consumption composed of both domestic goods and imported goods, we can obtain an open-economy generalization of the extended New Keynesian Phillips curve (NKPC) that incorporates an extended inflation dynamics and world excess demand, viz.

$$\pi_t = c + \gamma_e E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \sum_{i=1}^{m-1} \alpha_i \Delta \pi_{t-i} + \delta_d \hat{y}_t + \delta_f \hat{y}_t^* + \lambda_t, \tag{8}$$

where $\hat{y}_t$ and $\hat{y}_t^*$ denote domestic and foreign real output gaps, λ_t is an error term, and other coefficients are functions of structural parameters in the DSGE system illustrated in the appendix.

Note that model (8) introduces the globalization factor and more inflation dynamics (i.e., $\sum_{i=1}^{m-1} \alpha_i \Delta \pi_{t-i}$) into an extended NKPC model and provides a channel through which globalization may alter the dynamic response of inflation to domestic demand. If the impact of the world excess demand on inflation is trivial (insignificant), the model then reduces to a closed-economy version of NKPC. The inclusion of additional lag terms in the model is particularly important in order to obtain valid results in empirical estimations, since the stylized specification of the conventional NKPC model generally has a serial correlation problem (Zhang, Osborn, and Kim 2008). The possible presence of serial correlation is crucial for the choice of valid instruments for GMM estimations of the NKPC models, since all lags of the dependent variable are invalid instruments in the presence of autoregressive serial correlation. Since lags of inflation are typically employed as instruments for estimation of the NKPC, the consistency of these estimates depends on the lack of such serial correlation.

3. The Data

The baseline estimation of model (8) involves series for domestic inflation π_t; inflation expectations $E_t\pi_{t+1}$; a measure of the domestic output gap; and a measure of the foreign output gap $\hat{y}_t^*$. As will be discussed in section 4, the estimation of model (8) also involves effective federal funds rate and growth rate of monetary aggregate (i.e., M2) as instrumental variables. The raw (seasonally adjusted) data were obtained from the Federal Reserve Economic Data (FRED) database of the Federal Reserve Bank of St. Louis. The final series used in empirical estimations are stationary (confirmed by conventional unit-root tests). The sample size in our empirical estimations spans the first quarter of 1980 to the last quarter of 2012 (i.e., 1980:Q1–2012:Q4) dictated by availability of trade data. Available monthly data on consumer price index, federal funds rate, and M2 are transformed using end-of-quarter observations as the corresponding quarter values to avoid inducing serial correlation in the final data set.

Several issues of the data deserve further explanations. First, U.S. inflation is measured by the quarterly year-on-year growth rate of the consumer price index (CPI). Second, inflation expectations are unobservable and have to be approximated via an appropriate method. A commonly used method in the literature (e.g., Galí and Gertler 1999) is to approximate the unobserved inflation expectations in (8) by the corresponding realized future inflation, i.e., $E_t\pi_{t+1} = \pi_{t+1} - e_{t+1}$, where e_{t+1} denotes the rational prediction error. This approach, however, induces an extra disturbance to the underlying model which is likely to affect the accuracy of the estimation of the variance of the error term associated with the NKPC model. It also leads to econometric difficulties in the serial correlation test for the residuals in empirical estimations. To avoid these problems, we follow Pagan (1984) and approximate inflation expectations by projecting realized future inflation on the instrumental variable (IV) set

Z used in our empirical estimations (i.e., $E_t\pi_{t+1} = P_Z\pi_{t+1}$, where $P_Z = Z(Z'Z)^{-1}Z'$ is the projection matrix in terms of the IV set). It follows that this procedure will yield precisely the same coefficient estimates as those obtained by the IV estimation with the rational expectations approximation, while the standard errors will be different since the former ignores uncertainty in the estimation of the projection matrix (Pagan 1984).

Third, the real domestic output gap in the baseline estimations is obtained from the Hodrick-Prescott (HP) filter on the corresponding real GDP series (with smoothing parameter 1,600 for quarterly data). In robustness assessments, we also use deterministic linearly and quadratically detrended log real GDP to approximate the real output gap in model (8).

Fourth, the real foreign output gap is calculated as a weighted sum of the real GDP gap measure of the top ten U.S. major trading partners.[2] The weight for each trade partner in each year is determined by the percentage of the partner's total trade (exports and imports) to the United States over the total trade of the United States with the ten partners in that year. Table 1 presents the corresponding statistics for the trade weights of each of the ten countries to the United States over 1980–2012. It shows that the trade weights of different countries to the United States change over time. For example, the trade percentage of China to the United States witnessed a dramatic jump in the mid-1990s, rising from less than 5 percent before 1992 to above 7 percent in the late 1990s and around 20 percent over the most recent five years. Interestingly, however, the trade percentage of Japan to the United States has experienced a steady decline from the 1990s to the 2000s. After 2002, China took over Japan and became the second largest U.S. trading partner. A similar pattern of declining trade percentage to the United States can also be observed for Canada, which was the largest U.S. trading partner in most of the times.

These variations in the trade percentages are fully accounted for in the calculation of the foreign real GDP gap, i.e., $\hat{y}_t^* = \sum_{j=1}^{18} w_{j,t}\hat{y}_{j,t}$, where $w_{j,t}$ denotes the defined weight (i.e., trade

[2]The top ten major U.S. trading partners include Canada, China, France, Germany, Italy, Japan, Korea, Mexico, Netherlands, and the United Kingdom. The trade data and real GDP series for the ten countries were obtained from the International Monetary Fund.

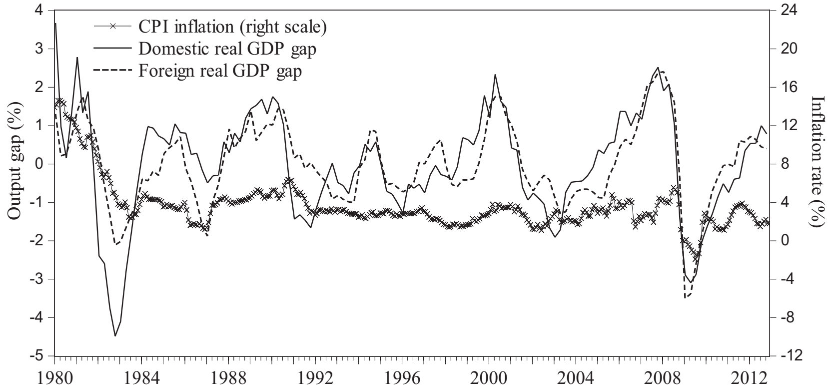
Table 1. Trade Percentage of U.S. Top Ten Major Trade Partners (%)

Year	CAN	CHN	FRA	GER	ITA	JAP	KOR	MEX	NETH	UK
1980	30.6	1.9	5.2	9.2	4.0	21.2	3.6	11.1	4.2	9.1
1981	30.9	2.0	4.8	7.9	3.9	22.1	3.8	11.4	4.0	9.2
1982	30.2	2.0	4.9	8.2	3.9	22.9	4.3	10.4	4.2	9.1
1983	32.5	1.7	4.4	7.9	3.5	23.5	4.9	9.4	3.9	8.4
1984	33.0	1.9	4.2	7.8	3.8	24.4	4.7	8.8	3.5	7.9
1985	31.6	2.2	4.4	8.2	4.1	25.7	4.5	8.9	3.2	7.3
1986	28.9	2.1	4.5	9.3	4.1	28.5	5.0	7.6	3.1	7.0
1987	29.9	2.4	4.4	9.0	3.9	26.4	5.9	8.0	2.8	7.3
1988	29.8	2.8	4.5	8.2	3.7	25.7	6.4	8.7	2.9	7.3
1989	30.0	3.4	4.5	7.6	3.6	25.4	6.1	9.4	3.0	7.1
1990	29.9	3.6	4.6	8.1	3.6	24.0	5.7	10.0	3.1	7.5
1991	29.6	4.4	4.8	8.0	3.5	23.7	5.5	10.8	3.1	6.8
1992	29.6	5.4	4.6	7.9	3.3	22.8	4.9	11.8	3.0	6.7
1993	30.8	6.1	4.2	7.0	2.9	22.8	4.7	11.9	2.7	7.0
1994	31.1	6.4	3.9	6.6	2.9	22.3	4.9	12.8	2.5	6.7
1995	31.0	6.8	3.6	6.8	3.0	21.7	5.7	12.3	2.6	6.4
1996	31.3	7.1	3.6	6.8	3.0	19.9	5.3	14.0	2.5	6.5
1997	31.2	7.6	3.7	6.7	2.8	18.4	4.7	15.4	2.7	6.8
1998	30.9	8.3	4.0	7.3	2.9	17.0	3.9	16.3	2.5	7.0
1999	30.9	8.5	3.9	7.1	2.8	16.4	4.6	16.7	2.4	6.7
2000	30.0	9.1	3.8	6.6	2.8	15.9	5.1	18.1	2.4	6.3
2001	29.9	10.0	4.0	7.1	2.7	14.6	4.6	18.3	2.3	6.5
2002	29.3	12.2	3.8	7.1	2.8	13.8	4.7	18.3	2.2	5.9
2003	29.3	14.2	3.5	7.3	2.8	12.8	4.6	17.5	2.4	5.7
2004	28.9	15.8	3.5	7.1	2.6	12.1	4.8	17.3	2.4	5.4
2005	29.2	17.5	3.3	7.0	2.6	11.5	4.3	17.0	2.4	5.3
2006	28.1	18.8	3.3	6.9	2.4	11.1	4.2	17.5	2.6	5.2
2007	27.7	19.8	3.4	7.2	2.5	10.4	4.1	17.1	2.6	5.3
2008	27.9	19.9	3.5	7.2	2.5	9.8	3.9	17.2	2.9	5.3
2009	25.5	22.3	3.6	6.8	2.3	8.8	4.1	18.1	2.9	5.5
2010	25.6	23.0	3.2	6.4	2.1	8.9	4.3	19.1	2.6	4.8
2011	25.8	22.4	3.0	6.4	2.2	8.5	4.4	19.9	2.9	4.6
2012	25.2	22.6	3.0	6.5	2.2	9.0	4.2	20.2	2.6	4.5

Note: The statistic is calculated as the ratio of the U.S. trade to each country as a percentage of total trade of the United States to all countries listed in the table; initial letters of each country's name are used as an acronym to represent the country.

percentage) at time t (quarterly observations within one year use the same weight of the year) and $\hat{y}_{j,t}$ is the real output gap measure for country j. Figure 2 plots the resulting foreign output gap series in conjunction with the U.S. real GDP gap and inflation series. It

Figure 2. U.S. Inflation, Domestic and Foreign Output Gaps: 1980:Q1–2012:Q4



Source: The author's calculations.

shows that the cyclical behavior of the domestic and foreign output gaps is similar in general but differs in details. In particular, the domestic GDP gap is more volatile than the foreign GDP gap before the late 1990s and vice versa during the most recent decade. This difference is reflected in the comparison of the dynamic evolution between domestic CPI inflation and the two output gaps: U.S. inflation appears to move more closely with the domestic output gap than with the foreign output gap before the late 1990s, and the scenario reverses afterwards. Whether this difference envisions structural changes in inflation dynamics model remains an empirical issue.

It may be noted that some studies (e.g., Martínez-García 2015) have shown that data quality and measurement issues also play an important role and may explain the lack of consensus as regards the effect of globalization on inflation in the literature. However, it should be noted that the relevant findings are different even if we examine the comparable results with similar data and measurement in the literature. Therefore, there is still room for model specification and structural break issues in accounting for the dispute on the nexus between globalization and inflation.

4. Empirical Results

4.1 Econometric Issues

As already noted in section 1 of this paper, the U.S. economic globalization level has increased substantially since the 1990s, and this change may shift the mechanism of the impact of globalization on the inflation dynamics. In particular, the empirical sample in our analysis covers a relatively long period from 1980 to 2012, which witnesses profound changes in the U.S. integration to the world economy and its macroeconomic dynamics. While the link between economic globalization and inflation dynamics makes it plausible that such changes may lead to structural breaks in the parameters of the NKPC model (8), any such effect and its timing depend on the behavior of economic agents. Since the dates of potential change points are therefore unknown, we perform break tests using the methodology proposed by Andrews (1993).

Prior to examining the structural break tests, several econometric issues in estimating the baseline model should be noted. First, inflation expectations in model (8) may be influenced by information relating to the current period. In addition, the real variables are also likely to be correlated with the contemporaneous noise, since demand shocks may influence both variables. Therefore, we use IV, or more generally the generalized method of moments (GMM) estimator to estimate model (8) and pin down the endogeneity problem.

The baseline IV set used in estimating (8) consists of two lags of each of the domestic and foreign output gaps, effective federal funds rate, and M2 growth rate, plus the lags of inflation included in the model (and a constant). The optimal lag order in the NKPC model (8) is specified by Akaike information criteria (AIC) and Godfrey's (1994) IV serial correlation test. In addition, the baseline estimations are verified through Hansen's (1982) J-test for over-identifying restrictions and the Stock and Yogo (2003) generalized F-test for weak IV.

Note that the Godfrey IV serial correlation test is implemented by adding appropriate lagged residuals from the initial estimation to the regressors from the initial model and checking their joint significance by the Lagrange multiplier (LM) principle. This test is

Table 2. Results of Andrews Unknown Break Point Tests for Model 8

	$\boldsymbol{all}$	$\boldsymbol{c}$	$\boldsymbol{\gamma_e}$	$\boldsymbol{\gamma_b}$	$\boldsymbol{\alpha_i}$	$\boldsymbol{\delta_d}$	$\boldsymbol{\delta_f}$
p-value	0.000	0.046	0.020	0.001	0.085	0.057	0.060
Break Date	2005:Q4	1987:Q1	1992:Q3	1991:Q3	1986:Q2	1990:Q4	1993:Q1

Notes: The estimated equation is given by model 8 with a sample spanning 1980:Q1–2012:Q4 prior to lag adjustment. Optimal autoregressive lag order in the NKPC model is specified by AIC and IV serial correlation test (with maximum eight lags). Inflation expectations are measured by fitted values of regressing the realized future inflation on the baseline IV set. The baseline IV set includes two lags of each of the domestic and foreign output gaps, effective federal funds rate, and M2 growth rate, plus the lags of inflation included in the model (and a constant).The structural break tests are implemented over central 70 percent of the underlying sample; break date corresponds to the break point at which the maximum test statistic is achieved.

used to check the possibility of serial correlation in the IV estimations with null hypothesis of no serial correlation. Therefore, a large p-value indicates no significant serial correlation in the regression and vice versa. The Stock-Yogo weak instrument test provides diagnostic information on to what extent the underlying instruments are weak in the estimation. The statistics reported are the Cragg-Donald statistics, with larger values indicating stronger IV sets.

Based on the preceding design, we carry out formal unknown structural break tests. Specifically, we employ the supreme likelihood ratio (LR) test of Andrews (1993) to test for unknown structural breaks in model (8). The test is designed to test for the null hypothesis of no structural break in the underlying parameters of interest. The corresponding p-values of the tests are computed using the method of Hansen (1997). We set a conventional searching interval of the central 70 percent of the full sample to allow a minimum of 15 percent of effective observations contained in both pre- and post-break periods to avoid extreme statistic results.

4.2 Baseline Results

Table 2 summarizes the results of the Andrews (1993) unknown structural break tests for model (8). The break tests are performed on all the coefficients overall and then on the individual coefficients.

Specifically, the first row in table 2 provides notational information for the coefficients in the break tests, with the first statistic (denoted *all*) testing for stability of all the coefficients in (8), while the other results refer to individual tests for the indicated coefficients. The second row reports p-values associated with the corresponding break test statistics for the null hypothesis of no structural change, while the third row, labeled *break date*, represents the estimated break date corresponding to the *Sup-LR* statistic.

As can be seen from the results in table 2, p-values for all break test statistics are quite small (significant at different significance levels), indicating structural instability of the underlying model. The break date statistics do not provide a uniform break point. Nonetheless, the structural break for the key coefficients of our interest, namely the coefficients on the domestic and foreign output gaps (δ_d *and* δ_f), as well as the forward- and backward-looking coefficients concentrates in the early 1990s. The break dates for the overall coefficients (*all*), the intercept (c), and the autoregressive coefficients (α_i) are close to the polar points in the searching interval and hence may be unreliable.

Since the structural break tests with unknown points fail to identify a clear break point for the underlying model, we need to produce additional empirical evidence based on a more comprehensive set of formal parameter constancy tests in support of the identified break points in the early 1990s. Therefore, we define dummy variables based on change points in 1990:Q4, 1991:Q3, 1992:Q3, and 1993:Q1 to investigate the nature of these structural breaks. Since our focus is the structural break in output gap measures and also to alleviate the associated collinearity induced by the multiplicative dummy variables, we use the following model to carry out dummy tests for each individual break point, viz.,

$$\pi_t = c + \gamma_e E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \sum_{i=1}^{m-1} \alpha_i \Delta\pi_{t-i} + \delta_d \hat{y}_t + \delta_f \hat{y}_t^* + \delta_d' \hat{y}_t d_t + \delta_f' \hat{y}_t^* d_t + u_t, \tag{9}$$

where d_t denotes the dummy variable with zero before the break point and unity otherwise.

Table 3. Results of Dummy Tests for Model 9

Break Point	1990:Q4	1991:Q3	1992:Q3	1993:Q1
δ'_d	-1.04^{**}	-1.66^{**}	-1.35	-1.647
	(0.433)	(0.718)	(0.927)	(1.205)
δ'_f	0.973^{**}	1.430	1.038	1.366
	(0.459)	(0.940)	(0.816)	(1.245)
Joint Test	0.059^{*}	0.021^{**}	0.344	0.310

Notes: The estimated equation is given by model 9 over the sample period from 1980:Q1 to 2012:Q4 prior to lag adjustment. The Bartlett kernel with Newey-West (fixed bandwidth) HAC-robust standard errors are reported in parentheses. "Joint Test" denotes the p-value for a joint significance test (F-statistic) for the coefficients on all dummy variables; * and ** denote statistical significance at the 10 and 5 percent levels, respectively.

The results for the dummy tests with the four possible break points are reported in table 3 using the sample 1980:Q1–2012:Q4. Conditional on the break point of 1990:Q4, both individual coefficient tests and the joint significance test are statistically significant, which provides clear evidence that the coefficients on both domestic and foreign output gap measures experience significant structural change in 1990:Q4. As a comparison, the joint test and tests for coefficients on the domestic output gap are significant (but the coefficient on the foreign output gap is not significant) for the break point of 1991:Q3. The similar results for the first two break points are unsurprising since these two points are very close to each other. For the break points of 1992:Q3 and 1993:Q1, the results do not provide clear evidence of a significant change in coefficients (all the dummy tests are insignificant).

Overall, the results of the structural break tests confirm that the inflation dynamics model (8) for the United States experiences a significant structural break in the early 1990s, and the evidence of change relates to the domestic and foreign output gaps as well as forward- and backward-looking components in the NKPC model. We have now obtained a structural break point based on which we can investigate the nature of changes in the United States' inflation dynamics and compare the impact of globalization on inflation dynamics over different sample periods when the break in the underlying coefficients is recognized at the early 1990s. In what follows, we will take the break date pertaining to the coefficient on the output gap (i.e., 1990:Q4) as the benchmark time to split the sample. The slightly different break points of 1991, 1992, and 1993 reported in table 2 will be examined in the robustness analysis. We will also evaluate the changing pattern of the coefficient estimates on the domestic and foreign output gap over recursive and rolling samples in the robustness analysis.

Table 4 reports GMM estimates of model (8) over the whole sample and pre- and post-1990 periods for the forward- and backward-looking inflation coefficients and the domestic and foreign output gap measures, in conjunction with relevant diagnostic statistics. The diagnostic test statistics in table 4 indicate that the specification of model (8) is generally free from significant serial correlation and the IV choice is valid and relatively strong in most cases. The p-values of the joint significance tests on the extra lagged inflation (from order two onwards) are smaller than 0.01 in all regressions, indicating a statistically significant role of the extra lagged inflation in the empirical NKPC model.

More importantly, the baseline results reported in panels A, B, and C in table 4 reveal significant changes in the impact of the domestic and foreign output gaps on U.S. inflation over different sample periods. Specifically, panel A shows that if the structural break is neglected, the domestic output gap drives inflation significantly with the coefficient estimate of 0.105. In contrast, the coefficient estimate on the foreign output gap is very small (-0.004) and statistically insignificant. Albeit the magnitude of the coefficient estimate on the domestic output gap declines when the convex restriction $\gamma_e + \gamma_b = 1$ is imposed, it is still much higher than the coefficient estimate on the foreign output gap and remains statistically significant.

When the structural break is accounted for, however, the results changed distinctively. Panel B and panel C provide evidence that the impact of the domestic and foreign output gaps on inflation has changed (switched) significantly before and after 1990. The coefficient estimate of the domestic output gap falls substantially from a large and significant value (0.166) pre-1990 to a small and insignificant value (0.001) post-1990. Conversely, the coefficient estimate of the foreign output gap has risen from an insignificant and small

Table 4. (GMM) Estimation Results of the Inflation Dynamics for the United States

Sample	Baseline Estimates				Diagnostic Tests			
	γ_e	γ_b	δ_d	δ_f	$p(\alpha_i)$	p-auto	p-J	WeakIV
A. 1980:Q1–2012:Q4								
	0.394***	0.567***	0.105***	−0.004	0.000	0.079	0.855	14.4###
	(0.018)	(0.07)	(0.011)	(0.005)				
$\gamma_e + \gamma_b = 1$	0.491***	0.509***	0.057***	0.019	0.000	0.034	0.884	14.4###
	(0.021)	(0.021)	(0.021)	(0.029)				
B. Pre-1990:Q4								
	0.320	0.630***	0.166*	−0.052	0.000	0.410	0.616	4.02
	(0.413)	(0.213)	(0.089)	(0.287)				
$\gamma_e + \gamma_b = 1$	0.444***	0.556***	0.128	−0.063	0.000	0.054	0.678	4.02
	(0.148)	(0.148)	(0.136)	(0.201)				
C. Post-1990:Q4								
	0.520***	0.454***	0.001	0.080*	0.000	0.057	0.587	6.33##
	(0.047)	(0.040)	(0.014)	(0.042)				
$\gamma_e + \gamma_b = 1$	0.539**	0.461***	−0.013	0.085**	0.000	0.003	0.846	6.33##
	(0.048)	(0.048)	(0.008)	(0.039)				

Notes: The estimated equation is given by model 8. Inflation expectations are measured by fitted values of regressing the realized future inflation on the baseline IV set (IV is the same as in table 2). The Bartlett kernel with Newey-West (fixed bandwidth) HAC-robust standard errors are reported in parentheses. $p(\alpha_i)$ is the p-value of a joint significance test on lagged inflation beyond order one; p-auto, p-J, and weakIV refer to p-values of Godfrey's (1994) IV serial correlation test, Hansen's (1982) J-test, and Stock and Yogo's (2003) weak instrumental variables test (critical values for the weak IV test are provided in Stock and Yogo 2003), with ####, ###, ##, and # denoting statistically signficantly strong IV (at the 5 percent significance level) when the desired maximal bias of the IV estimator relative to OLS is specified to be 5, 10, 20, and 30 percent, respectively. *, **, and *** denote statistical significance at the 10 percent, 5 percent, and 1 percent levels, respectively.

negative value (−0.05) to a significant and positive value (0.08). A similar scenario can be observed when the convex restriction is imposed.

The results in table 4 suggest that there is a significant decline in the sensitivity of U.S. inflation to the domestic output gap since the early 1990s. In addition, the impact of globalization, as captured by the foreign output gap, on domestic inflation has increased dramatically since 1990. The comparison between the coefficient estimates on the domestic and foreign output gaps clearly shows that the foreign output gap plays a more prominent role than the domestic counterpart in the domestic inflation process after 1990.

To summarize, the coefficient estimates of the domestic and foreign output gap measures provide our main finding from table 4, namely that the impact of the domestic and foreign output gaps on U.S. inflation has changed significantly. The foreign output gap plays a more important role than the domestic output gap in affecting the domestic inflation process over the most recent two decades. This finding indicates that inflation dynamics in the United States has shifted significantly since the early 1990s and the impact of globalization via the foreign excess demand has indeed risen accordingly. The next section assesses the robustness of this finding.

4.3 Robustness Assessments

To assess the robustness of the baseline finding that the impact of globalization on inflation dynamics has changed, we carry out three sets of sensitivity exercises. First, we investigate whether the finding is robust to slightly different break points of 1991, 1992, and 1993, which are shown in table 2. Second, we assess the robustness of the baseline finding by dropping the domestic and foreign output gap from the NKPC model. If the foreign economic slack does not exert any influence on the sensitivity of inflation to the domestic output gap, the coefficient estimates on the domestic output gap in models with and without foreign output gap should be similar. Third, we examine recursive estimates of the coefficients on the domestic and foreign output gaps to provide further evidence on the changing pattern of the impact of globalization on inflation in the United States.

Table 5 reports the results for the first exercise. Panel A shows that the domestic output gap is significant for the pre-1991 period but insignificant (and small) for the post-1991 era, while the converse applies to the foreign output gap. The results for break points being 1992 and 1993 in panels B and C provide a similar scenario as the baseline finding. Although the coefficients on the foreign output gap are statistically insignificant over the post-break periods (which may be unsurprising because the underlying variables in the model have been very smooth during these periods), the comparison between the coefficient estimates on the domestic and foreign output gaps clearly shows that the foreign output gap plays a more prominent role than the domestic counterpart in the domestic inflation process after the early 1990s.

However, obtaining statistical significance for the foreign output gap over the post-1990 period is difficult. Conditioning on the alternative break points after 1990:Q4, the coefficient of the global output gap is no longer statistically significant. Based on these results, one might argue that the empirical evidence in support of the globalization hypothesis is weak from the perspective of statistical significance. The statistical insignificance, however, may reflect the fact that the break point for the foreign output gap is different from those for other variables in the model. In addition, although the statistical significance for the foreign output gap is not clear from table 5, the following additional exercises provide further evidence and confirm the changing role of the domestic and foreign output gap in driving domestic inflation.

Table 6 summarizes the results for the second exercise. Panel A and panel B provide the estimation results when either the domestic or foreign output gap is dropped from the NKPC model. It appears to be difficult to distinguish the roles of the domestic and foreign output gaps in affecting the inflation process before 1990 in terms of the magnitude of the coefficient estimates, but statistically speaking, the domestic output gap is significant while the foreign output gap is insignificant. For the post-1990 period, it is clear that the domestic output gap plays a small and insignificant role but the foreign output gap plays a large and significant role in driving domestic inflation. These results reinforce the conclusion that the foreign economic slack plays a more important role than the domestic output in affecting U.S. inflation after the early 1990s.

Table 5. Robustness: Alternative Break Dates

	Baseline Estimates				Diagnostic Tests			
	γ_e	γ_b	δ_d	δ_f	$p(\alpha_i)$	p-auto	p-J	WeakIV
A. Break = 1991:Q3								
Pre-1991	0.323	0.631***	0.166*	−0.058	0.000	0.433	0.605	4.35
	(0.189)	(0.120)	(0.096)	(0.157)				
Post-1991	0.519***	0.466***	−0.041	0.121	0.000	0.057	0.693	6.72##
	(0.068)	(0.102)	(0.088)	(0.172)				
B. Break = 1992:Q3								
Pre-1992	0.306***	0.639***	0.165***	−0.060	0.000	0.469	0.566	4.54#
	(0.026)	(0.025)	(0.029)	(0.058)				
Post-1992	0.532***	0.462***	−0.051	0.129	0.000	0.059	0.681	7.55##
	(0.115)	(0.088)	(0.197)	(0.375)				
C. Break = 1993:Q1								
Pre-1993	0.307***	0.640***	0.165*	−0.063	0.000	0.516	0.542	3.85
	(0.161)	(0.109)	(0.094)	(0.167)				
Post-1993	0.543***	0.466***	−0.055	0.126	0.000	0.055	0.705	8.09##
	(0.062)	(0.084)	(0.074)	(0.174)				

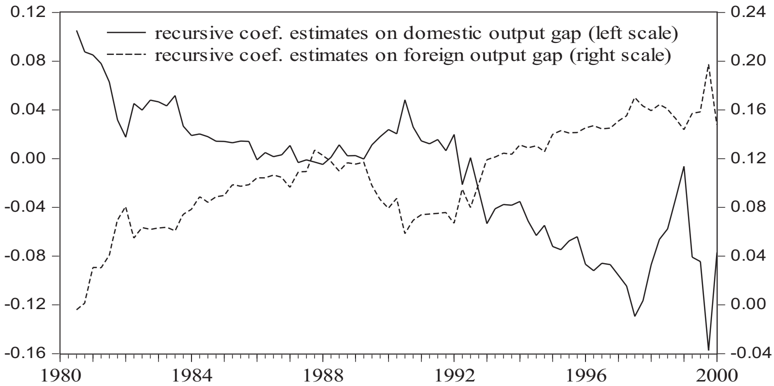
Notes: See table 4.

Table 6. Robustness: Dropping Domestic or Foreign Real Variables

Sample	Baseline Estimates				Diagnostic Tests			
	γ_e	γ_b	δ_d	δ_f	$p(\alpha_i)$	p-auto	p-J	WeakIV
A. Pre-1990								
No Foreign	0.290	0.646***	0.144*		0.000	0.367	0.565	5.05#
	(0.247)	(0.162)	(0.084)					
No Domestic	0.504**	0.477***		0.154	0.000	0.133	0.671	4.54
	(0.204)	(0.108)		(0.225)				
B. Post-1990								
No Foreign	0.537***	0.454**	0.070		0.000	0.091	0.671	17.47####
	(0.118)	(0.184)	(0.096)					
No Domestic	0.394***	0.463***		0.106**	0.000	0.028	0.840	16.62####
	(0.036)	(0.100)		(0.063)				

Notes: "No Foreign" means that the regression excludes the foreign output gap, and "No Domestic" is defined analogously; other notations follow table 5.

Figure 3. Recursive Estimates of δ_d and δ_f

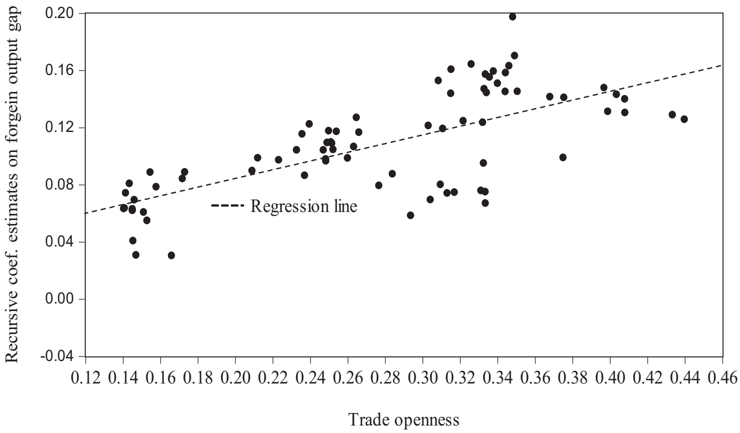


Note: Recursive samples start from 1980:Q1 to 2000:Q1 with the end period 2012:Q4 being fixed.

The design of the third exercise provides another useful check on the robustness of the baseline finding over recursive samples. By construction, the recursive estimations produce coefficient estimates on the domestic and foreign output gaps over the recursive samples starting from 1980 onwards with the end period (2012:Q4) fixed. By looking at the recursive estimates, we can (presumably) evaluate the changing pattern of the coefficient estimates on the domestic and foreign output gaps. Figure 3 plots the results of the recursive estimations. It shows that the coefficients on the domestic output gap generally manifest a declining trend while the coefficients on the foreign output gap grow over the forward recursive samples. This result is consistent with our finding of the increasingly important role of the foreign economic slack in affecting domestic inflation. Although the recursive estimates might not be very accurate by nature, the results corroborate the finding of a great deal of the baseline empirical work.

Based on the recursive estimates, we further obtain the scatter plot of the coefficient estimates for the foreign output gap against globalization (i.e., trade openness) over time (1980:Q1–2001:Q1) in figure 4. The upward-sloping regression line fitted in the scatter plot suggests that the coefficient estimates on the foreign output gap in general move in the same direction as the level of U.S. economic

Figure 4. Scatter Plot of Recursive Estimates of δ_f against Trade Openness (1980:Q1–2001:Q1)



globalization. This result indicates that the impact of the foreign output gap on inflation increases when the level of U.S. economic globalization rises.

5. Discussion

The empirical results in section 4 provide evidence of a significant structural break in the NKPC model for the United States. The results also indicate that the roles that domestic and foreign economic slack played in U.S. inflation have switched in the early 1990s: the foreign output gap exerts larger impact than the domestic output gap on inflation since the early 1990s. Omitting such a structural break, as the results pertaining to the whole sample estimation indicate, can lead to a fragmented conclusion that the domestic output gap plays a predominant role in the inflation process during the entire period of the past three decades.

The important role of the foreign output gap in the NKPC model since the 1990s raises a realistic concern that the problems facing the Federal Reserve are likely to be complicated by the rising economic globalization of the U.S. economy. More specifically, because the Phillips curve is an indispensable component in monetary policy analysis, it is natural that the impact of the globalization factor on inflation can also transmit to other macroeconomic variables in policy analysis frameworks. Suppose we analyze the issue in a standard three-equation model as in Woodford (2009) with an IS curve, a Phillips curve, and a policy reaction function. The impact of globalization on inflation will transmit to domestic real output through the IS curve and to monetary policy via the policy reaction function.

Interestingly, however, Woodford (2009) carries out a formal theoretical analysis on the possible impact of globalization on this traditional monetary policy transmission process, and his simulation results appear to suggest that increased globalization engenders no substantial reduction of the effects of domestic monetary policy on the domestic economy. Through the theoretical designs, Woodford provides a comprehensive and valuable discussion on a wide range of ways that globalization might weaken the central bank's ability to influence the economy.

Woodford carefully interprets in his conclusion that his results mainly suggest that increased globalization should not eliminate the influence of domestic monetary policy over domestic inflation, but do not mean that the degree of openness of an economy is of no significance for the conduct of monetary policy. Indeed, increased international trade in financial assets, consumer goods, and factors of production should lead to quantitative changes in the magnitudes of various key response elasticity relevant to the transmission mechanism for monetary policy (Woodford 2009). In particular, changes in the degree of goods market integration affect the quantitative specification of both the aggregate demand and aggregate supply blocks in Woodford's analysis.

Our work also provides empirical results that are complementary to the comprehensive studies of Mishkin (2007, 2009) which articulate that the decline in the sensitivity of inflation to the domestic output gap in the United States is the result of better monetary policy that has anchored inflation expectations. Our results do not exclude the potential contribution of better monetary policy on the flattening of the Phillips curve. The finding does not mean that the rising globalization of the U.S. economy will eliminate the Federal Reserve's capacity to stabilize domestic inflation, nor do we regard the rising globalization as a fatal fear to the national economy. The bottom line, however, is that the central bank can gear up its capacity to control inflation by appropriate coordination with other central banks. Even without material coordinated actions, the central bank may still be able to increase the precision of its relevant forecasts and thereby improve the effect of its policies on domestic economy by adding the global development into its forecasting information set or augmenting its policy analysis framework with globalization factors.

On a minimum (and positive) side, the baseline finding in the present paper calls attention to the rising globalization that may engender material forces for central bankers to confront more practical issues than the traditional issues in a closed economy. The changing degree of globalization also makes the issue of change over time in the correct quantitative specification of the models used in a central bank a more pressing one to consider (Woodford 2009).

6. Conclusions

The past three decades have been characterized by a steady progress of global economic integration. The U.S. economy has also become increasingly more open. This progress of globalization may have led to important changes in U.S. inflation dynamics. This paper constructed an extended New Keynesian Phillips-curve model from microeconomic foundations and showed that globalization factors (i.e., foreign output gap) can be incorporated into such a model. We proposed that this model may have experienced structural breaks given the fact that the level of globalization of the U.S. economy has changed substantively over the period of 1980 to 2012.

Our empirical investigations showed that there is a significant structural change in the early 1990s in the extended NKPC model for the United States, after which inflation responds much more to the foreign economic slack than to the domestic output gap. This finding indicates that the Federal Reserve should take into account the developments in global economic performance in the monetary policymaking process. It further implies that while the higher level of globalization may help subdue and stabilize domestic inflation by, for example, stabilizing global economic slack during globally tranquil times, a negative global economic environment can also present extra challenges for the domestic policymakers. Therefore, studies that neglect the role of foreign economic slack are likely to underestimate the impact of globalization factors on domestic inflation dynamics, at least for the period post-1990.

Appendix

This appendix provides details in developing a dynamic, micro-founded inflation dynamics model for an open economy with sticky prices. The model is an extension of recent developments in the open-economy dynamic stochastic general equilibrium literature. To facilitate notations, we will use variables with an i-index to refer to economy i and variables without an i-index to refer to the open economy being modeled. Variables with subscripts D and F refer to domestic variables and foreign variables, respectively, while variables with a star superscript refer to the world economy as a whole.

Households

The objective of a representative household in a typical open economy is to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t), \tag{10}$$

where N_t denotes labor services provided by the household, and C_t is a composite consumption index composed of consumptions of both domestic goods and imported goods, viz.

$$C_t \equiv \left[(1-a)^{\frac{1}{\eta}} (C_{D,t})^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} (C_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{11}$$

where $C_{D,t}$ and $C_{F,t}$ are indexes for consumptions of domestic and imported goods, respectively, both of which are consumed by domestic households and given by the continuum version of the standard constant elasticity of substitution (CES) function. Parameter α is related to the degree of home bias in preferences, and parameter η measures the substitutability between domestic and foreign goods, from the perspective of the domestic consumers.

The maximization of (10) is subject to a sequence of budget constraints of the form

$$\int_0^1 P_{D,t}(j)C_{D,t}(j)dj + \int_0^1 \int_0^1 P_{i,t}(j)C_{i,t}(j)djdi + E_t(Q_{t,t+1}Z_{t+1}) \leq Z_t + W_t N_t + T_t, \quad (12)$$

where $P_{D,t}(j)$ is the price of variety j produced domestically and $P_{i,t}(j)$ is the price of variety j imported from country i (expressed in domestic currency). Z_{t+1} is the nominal payoff in period $t+1$ of the portfolio held at the end of period t, W_t denotes the nominal wage, T_t denotes lump-sum taxes, and $Q_{t,t+1}$ is the stochastic discount factor for one-period-ahead nominal payoffs relevant to the domestic household.

In the open economy, the households' demand functions can be categorized as

$$C_{D,t}(j) = \left(\frac{P_{D,t}(j)}{P_{D,t}}\right)^{-\varepsilon} C_{D,t}, C_{i,t}(j) = \left(\frac{P_{i,t}(j)}{P_{i,t}}\right)^{-\varepsilon} C_{i,t}, \quad (13)$$

where $P_{D,t}(j) \equiv (\int_0^1 P_{D,t}(j)^{1-\varepsilon}dj)^{\frac{1}{1-\varepsilon}}$ is the price index for goods produced domestically, $P_{i,t}(j) \equiv (\int_0^1 P_{i,t}(j)^{1-\varepsilon}dj)^{\frac{1}{1-\varepsilon}}$ is a price index for goods imported from country i, and ε is the elasticity of substitution between varieties.

Let $P_{F,t} \equiv (\int_0^1 P_{i,t}^{1-\gamma}di)^{\frac{1}{1-\gamma}}$ be the price index for imported goods (where γ measures the substitutability between goods produced in different foreign countries); the optimal allocation of consumptions on imported goods by country of origin implies

$$C_{i,t} = \left(\frac{P_{i,t}}{P_{F,t}}\right)^{-\gamma} C_{F,t}. \quad (14)$$

Since domestic households' consumptions are composed of domestically produced goods and imported goods, the overall domestic price index (DPI) can be written as $P_t \equiv [(1-\alpha)(P_{D,t})^{1-\eta} + \alpha(P_{F,t})^{1-\eta}]^{\frac{1}{1-\eta}}$. As such, the optimal allocation of consumptions between domestic and imported goods is given by

$$C_{D,t} = (1-\alpha)\left(\frac{P_{D,t}}{P_t}\right)^{-\eta} C_t, \quad C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t. \quad (15)$$

Accordingly, total consumption by domestic households is given by $P_{D,t}C_{D,t} + P_{F,t}C_{F,t} = P_tC_t$. Thus the period budget constraint can be rewritten as

$$P_tC_t + E_t(Q_{t,t+1}Z_{t+1}) \leq Z_t + W_tN_t + T_t. \tag{16}$$

In addition, we assume the period utility function takes the form $U(C,N) \equiv (1-\sigma)^{-1}C^{1-\sigma} - (1+\varphi)^{-1}N^{1+\varphi}$. The remaining optimality conditions for the households' problem can be written as

$$C_t^{\sigma}N_t^{\varphi} = W_t/P_t \tag{17}$$

and

$$\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right) = Q_{t,t+1}. \tag{18}$$

Taking conditional expectations on both sides of (18), we obtain a stochastic Euler equation

$$\beta R_t E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right)\right] = 1, \tag{19}$$

where $R_t = (E_tQ_{t,t+1})^{-1}$ denotes the gross return on a risk-free one-period discount bond.

It is useful to note that (17) and (19) can be respectively written in log-linearized form as

$$\begin{cases} w_t - p_t = \sigma c_t + \varphi n_t \\ c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}(r_t - E_t\{\pi_{t+1}\} - \rho), \end{cases} \tag{20}$$

where lowercase letters denote the natural logarithm of the respective variables, $\rho \equiv \beta^{-1} - 1$ is the time discount rate, and $\pi_t \equiv p_t - p_{t-1}$ (with $p_t \equiv Ln(P_t)$) is the overall domestic price inflation.

In what follows we define the bilateral terms of trade between the domestic economy and country i as $S_{i,t} = P_{i,t}/P_{D,t}$. The effective terms of trade can be approximated by the log-linear expression $s_t = \int_0^1 s_{i,t}di$. Combining the definition of P_t in (15) with the purchasing power parity (PPP) condition, we can obtain the link between the DPI, $P_{D,t}$, and $P_{F,t}$, which can be further used to obtain the relationship between overall domestic price inflation π_t (defined as the rate of change in the index of overall domestic goods prices) and domestically produced goods price inflation $\pi_{D,t}$, viz.

$$\pi_t = \pi_{D,t} + \alpha \Delta s_t. \tag{21}$$

Let $e_t \equiv \int_0^1 e_{i,t} di$ denote the log nominal effective exchange rate and $p_t^* \equiv \int_0^1 P_{i,t}^i di$ denote the log world price index. Assuming that the law of one price holds at all times and combining the definition of $P_{F,t}$ in (14) with the definition of the terms of trade, we can obtain the linear expression for the terms of trade, the domestic price, and the world price as

$$s_t = e_t + p_t^* - p_{D,t}. \tag{22}$$

Let $q_t = \int_0^1 q_{i,t} di$ be the log effective real exchange rate (where $q_{i,t}$ is the log bilateral real exchange rate). It follows that

$$q_t = s_t + p_{D,t} - p_t = (1 - \alpha) s_t. \tag{23}$$

Next, we consider the relationship between domestic consumption expenditures and the world consumption expenditures. As in Galí and Monacelli (2005), a first-order condition analogous to (18) also holds for the household in any other country i, viz.

$$\beta \left(\frac{C_{t+1}^i}{C_t^i} \right)^{-\sigma} \left(\frac{P_t^i}{P_{t+1}^i} \right) \left(\frac{\varpi_t^i}{\varpi_{t+1}^i} \right) = Q_{t,t+1}, \tag{24}$$

where ϖ denotes bilateral nominal exchange rate. Combining (18), (23), and (24), we obtain

$$c_t = c_t^* + \frac{1}{\sigma} q_t = c_t^* + \left(\frac{1 - \alpha}{\sigma} \right) s_t, \tag{25}$$

where $c_t^* \equiv \int_0^1 c_t^i di$ is the log world consumption index.

Firms

We assume that a typical domestic firm produces differentiated goods with a linear technology represented by the production function of $Y_t(j) = A_t N_t(j)$, A_t denotes technology, and N_t is defined as in (10). Hence, the real marginal cost is given by

$$mc_t = -v + w_t - p_{D,t} - a_t, \tag{26}$$

where $v \equiv -\log(1-\tau)$ (τ denotes an employment subsidy) and $a_t \equiv \ln(A_t)$. Let y_t be the log domestic real output, analogously defined as the one introduced for consumption. It can be shown that

$$y_t = a_t + n_t, \tag{27}$$

where $n_t \equiv \log(N_t)$.

For the pricing behavior of the domestic firms, we assume an economic environment similar to Calvo's (1983) model, in which firms are able to revise their prices in any given period with a fixed probability $(1-\theta)$. In addition, we assume both "forward-" and "backward-looking" firms coexist in the economy with a proportion of ω and $(1-\omega)$, respectively. Further, we extend the rule of the recent pricing behavior of the backward-looking firms to incorporate a weighted process of past inflation, instead of stylized one lag of inflation inertia.

Specifically, based on the regular assumptions in Calvo's model and log-linear approximations, it is possible to obtain the (log) aggregate price level by

$$p_t = \theta p_{t-1} + (1-\theta)p_t^{new}, \tag{28}$$

where p_t^{new} is the new price set in period t. Let p_t^f be the price set by forward-looking firms and p_t^b be the price set by backward-looking firms at time t. The new price (relative to the aggregate price) can be expressed as a convex combination of p_t^f and p_t^b, viz.

$$p_t^{new} - p_t = \omega(p_t^f - p_t) + (1-\omega)(p_t^b - p_t). \tag{29}$$

Next, following Woodford (2003), the pricing behavior of the forward-looking firms can be written as

$$p_t^f - p_t = \theta\varsigma \sum_{s=0}^{\infty} (\theta\varsigma)^s E_t \pi_{t+s+1} + (1-\theta\varsigma) \sum_{s=0}^{\infty} (\theta\varsigma)^s E_t mc_{t+s}, \tag{30}$$

where ς denotes a subjective discount factor. Iterating (30) gives

$$p_t^f - p_t = \theta\varsigma E_t \pi_{t+1} + (1-\theta\varsigma)mc_t + \theta\varsigma E_t(p_{t+1}^f - p_{t+1}). \tag{31}$$

Assume a rule of thumb in the pricing setting, viz.

$$p_t^b - p_t = p_{t-1}^{new} - p_t + \pi_{t-1}. \tag{32}$$

As emphasized in the literature, this is an elegant innovation in that the backward-looking firms can now set their prices to the average price determined in the most recent price adjustments with a correction for inflation. However, inflation inertia in (32) is confined to one single lag, which may neglect the importance of other historical inflation in predicting current inflation. Therefore, it would be more reasonable to replace π_{t-1} in (32) with a weighted average of inflation over several periods in the past. This modification effectively mitigates a serial correlation problem in empirical analysis. As such, we extend (32) in the following process:

$$p_t^b - p_t = (p_{t-1}^{new} - p_t) + \pi_{t-1} + \rho^*(L)\Delta\pi_{t-1}, \tag{33}$$

where $\rho^*(L) = \rho_1^* + \rho_2^* L + \cdots + \rho_m^* L^{m-1}$ is a polynomial in lag operator.

Combining (28)–(33), it can be shown that the dynamics of domestic inflation in terms of real marginal cost are described by an equation analogous to the one associated with a closed economy, viz.

$$\pi_t = \gamma_e E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \sum_{i=1}^{m-1} \alpha_i \Delta\pi_{t-i} + \lambda mc_t, \tag{34}$$

where coefficients of (34) are functions of the deeper parameters in (28)–(33).

Equilibrium and Inflation Dynamics Model

Combining goods market clearing conditions in the open economy with the definition of aggregate domestic output, we can obtain the following expression:

$$y_t = c_t + \alpha\gamma s_t + \alpha(\eta - \sigma^{-1})q_t = c_t + \frac{\alpha\varpi}{\sigma} s_t, \tag{35}$$

where $\varpi \equiv \sigma\gamma + (1-\alpha)(\sigma\eta - 1)$. Additionally, combining the world goods market clearing conditions with (18), (24), and (25), we can derive the relationship between real domestic output and real world output as

$$y_t = y_t^* + \frac{1}{\sigma_\alpha} s_t, \tag{36}$$

where $\sigma_\alpha \equiv [(1-\alpha) + \alpha\omega]^{-1}\sigma$.

Next, making use of (20), (25), (27), and (35), we can rewrite (26) as

$$mc_t = v + xi_d y_t + \xi^* y_t^* + u_t, \tag{37}$$

where $\xi_d \equiv (\sigma_\alpha + \varphi)$, $\xi^* \equiv (\sigma - \sigma_\alpha)$, and $u_t \equiv -(1+\varphi)a_t$. By definition of the real output gap (log-deviation from a steady-state level of output), the equation (37) can be rewritten as

$$mc_t = c^* + \xi_d \hat{y}_t + \xi^* \hat{y}_t^* + u_t, \tag{38}$$

where $c^* \equiv -v + \mu(\xi_d + \xi^*)$, and $\hat{y}_t$ and $\hat{y}_t^*$ are the real domestic output gap and the real world output gap, respectively.

Substituting (38) for mc_t in (34), we obtain an open-economy generalization of the extended New Keynesian Phillips curve (NKPC) that incorporates richer inflation dynamics and world excess demand, viz.

$$\pi_t = c + \gamma_e E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \sum_{i=1}^{m-1} \alpha_i \Delta\pi_{t-i} + \delta_d \hat{y}_t + \delta_f \hat{y}_t^* + \bar{\lambda}_t, \tag{39}$$

where $c \equiv \lambda c^*$, $\delta_d \equiv \lambda\xi_d$, $\delta_f \equiv \lambda\xi^*$, and $\bar{\lambda}_t \equiv \lambda u_t$.

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