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THE GROWTH-INFLATION NEXUS FOR THE U.S. FROM 1801 TO 2013: A SEMIPARAMETRIC APPROACH

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We study the existence of a threshold level of inflation for the U.S. economy over 1801-2013, beyond which it has a negative effect on economic growth. A combination of nonparametric (NP) and instrumental variable semiparametric (SNP-IV) methods obtain inflation thresholds for the United States. The results suggest that the relationship between growth and inflation is hump shaped –that higher levels of inflation reduce growth more compared to low inflation or deflation. The strongest result to emerge from the study consistently shows that inflation above two per cent negatively affects growth. Two additional parametric methods confirm this finding. Another important result is that high or very low levels of inflation are undesirable and are associated with lower growth - hinting that a growth maximizing value of inflation exists.

JEL classification codes: C14, E31
Key words: inflation, growth, nonparametric, semiparametric

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I. Introduction

What rate of inflation is unfavorable for economic growth? This paper shows that inflation above two per cent reduces GDP growth. We analyse the inflation-growth trade-off in a semiparametric model using 213 years of United States GDP and inflation data. This paper contributes to the existing literature with a specific focus on the United States and avoids assumptions regarding explicit functional relationships.

The inflation-growth trade-off is interesting for various reasons. Its policy relevance relates to making decisions regarding interest rates and understanding the endogenous response of output growth to inflation. With interest rates at the zero lower bound (ZLB), it is natural to ask what rate of inflation is optimal. This is equally important when the Federal Reserve (Fed) considers the rate of inflation that reduces the probability of hitting the ZLB. However, rising inflation expectations have economic costs –a decrease in GDP growth. The literature on the inflation–growth nexus shows mixed results on the level of inflation that subtracts from economic growth. If certain rates of inflation increase growth, then one might make the argument for raising the inflation target. This is a Mundell-Tobin effect where inflation expectations shift investments away from money balances into other types of capital that have growth inducing effects.

The so-called point at which inflation has a negative effect on economic growth has policy consequences. Consequently, many studies attempt to pinpoint the exact inflation threshold. The empirical methods used are diverse and cover nonlinear functional forms (to test possible hump-shaped relationships) to linear regressions estimated over certain break points to dynamic models that are estimated over certain periods (i.e., rolling window regressions) and panel models that take account of cross-sectional heterogeneity.

The large body of research that analyses inflation thresholds imposes a functional form (see Barro 1995; Fischer 1993 and Rousseau and Wachtel 2001 as an example) –a practice that might be wrong. Our paper comes perhaps closest to Vaono and Shiavo (2007), who use nonparametric methods in a panel framework to study possible inflation thresholds. They use a panel data set that includes 85 countries from 1960 to 1999 over five year period intervals. We depart from their work by focusing on obtaining results for the U.S. using a novel data set with a much longer and recent time series. We use instrumental variable (IV) methods to control for possible endogeneity between growth and inflation in a semiparametric model. This gives us an unbiased model free from assuming a functional form that imposes a nonlinear relationship or one that assumes inherent structural breaks, i.e., we let the data speak for itself. In addition to the nonparametric approach, we use various nonlinear parametric methods for robustness. Specifically, we test for inflation thresholds and its impact on economic growth using a time varying parameter and a smooth transition regression.

II. Literature review

It is generally accepted that inflation reduces overall welfare. The welfare costs of inflation have been extensively studied for the U.S. The general consensus is that inflation reduces overall welfare irrespective of discretionary or committed monetary policy. As an example, Miller et al. (2014) estimate the time-varying welfare costs of inflation in a money demand model using a time-varying cointegrated model. Their estimate of the welfare cost of 10 per cent inflation in terms of GDP range between 0.025 and 0.75 per cent, with an average of 0.27 per cent. This is well in line with other studies (see Fischer 1981; Serletis and Yavari 2004 and Ireland 2009).

From a theoretical perspective, Billi (2011) studies the optimal long-run rate of inflation in a New-Keynesian model that counteracts the negative economic effects of hitting the ZLB. Billi (2011) obtains estimates of the long-run inflation rate under three regimes (discretion, commitment and a Taylor rule) and implicitly accounts for misspecification in all cases. Under commitment policy, the optimal inflation rate is 0.2% (under no misspecification) and 0.9% (extreme misspecification) whereby the government hits the zero-lower-bound only occasionally. The government can stimulate the economy by creating inflation expectations and commitment implies a lowering of real interest rates. The consumption (welfare) loss is lower in the model with commitment compared to the model with discretion. The optimal long run inflation rate is very high if a government re-optimises (discretion) and extremely high accounting for misspecification. This causes high inflation expectations that could lead to high real interest rates that harm the economy. The optimal inflation rate can be as high as 13.4% and 16.7% (under extreme misspecification). Finally, under a standard Taylor rule the optimal long run inflation rate is between 8% and 9.8% (this rule does not account for inertial interest rates). Consumption loss is lowest in the model with an inertial Taylor rule (as opposed to a standard Taylor rule, commitment, and re-optimizing government) - this allows for slightly higher optimal long run inflation target. Billi (2011) shows that discretionary policy makers are so averse to deflation, that they are willing to tolerate massive inflation bias. This model, however, assumes that the monetary policy rate is the only policy measure available.

Reifschneider and Williams (2000) find a 2% inflation goal to be a sufficient level to counter the adverse economic effects of the ZLB. The frequency of mild recessions, due to the ZLB on the interest rate, are reduced for a two per cent inflation target compared to a zero per cent inflation target. However, the frequencies of severe recessions are higher in a model of two per cent inflation target relative to a zero inflation target.

Krugman (1998) interestingly states that committed inflation policy is a reason that economies remain at the ZLB: agents perceive expansionary monetary policy as temporary and believe the central bank's commitment to low inflation. A higher inflation commitment or alternative government policies might help an economy escape from the ZLB. Unfortunately, the Krugman study ignores the cost of higher inflation. However, Billi (2011) shows that the welfare costs of inflation are low when escaping the ZLB.

Khan and Senhadji (2001) estimate the inflation threshold of about 11% for developing countries and 1% for industrialized countries. They use a data set that covers 140 countries from 1960-1998. They use an indicator function to test the statistical significance of various thresholds. The inflation value that minimizes the sum of squared residuals of their specification is the inflation threshold. Burdekin et al. (2004) show that inflation (as low as single digit inflation) has a negative impact on economic growth. They estimate a spline equation that allows for structural breaks in inflation. This allows them to study the impact of inflation on growth at various thresholds. The growth cost of inflation becomes more pronounced at inflation levels in excess of 50%. Furthermore, they show that the inflation impact on growth is biased downwards when not accounting for nonlinearities.

Barro (1995) shows that a ten per cent increase in inflation reduces growth in real GDP per capita by about 0.2-0.3 percentage points per year –a significant reduction of GDP over a long period, which highlights the importance of price stability from a GDP perspective. This is in line with a plethora of panel studies that obtain similar results (see Roubini and Sala-i-Martin 1992; Fischer 1993 and Chari et al. 1995)

Bruno and Easterly (1998) show, however, that the negative association between inflation and economic growth is difficult to establish for low to moderate levels of inflation in a panel of 31 countries –they emphasise that pooled cross-country datasets are not informative about what happens to growth at low levels of inflation; something that this paper tries to remedy.

Vaona and Schiavo (2007) shows that the relationship between inflation and growth is nonlinear. They use nonparametric and semi-parametric IV methods to estimate thresholds. They obtain a 12 per cent threshold for developed countries while no clear indication of a threshold is found for developing countries.

Vaona (2012) finds a different result than Vaona and Schiavo (2007) using a similar methodology on a different dataset of 85 countries: inflation has a negative linear impact on growth; inflation is simply growth reducing.

III. Methodology

We use annual real GDP growth and inflation data from 1801 to 2013 calculated as percentage change of the real GDP (at constant 2009 prices) and the consumer price index (with a base period of 1982-1984). Real GDP data comes from the Global Financial Database, the CPI data comes from the website of Professor Robert Sahr.[1] The start and endpoints of our sample are purely driven by data availability; though the CPI data goes as far back as 1774, real GDP data is only available from 1800. Since we use growth rates of the two variables, we lose the observations corresponding to 1800. We control for different lags of inflation and GDP. This gives us 213 observations over different regimes and possible structural breaks. Inflation over the period averaged 1.37 per cent while GDP growth averaged 3.65 per cent (see Table 1).

Table 1. Descriptive statistics

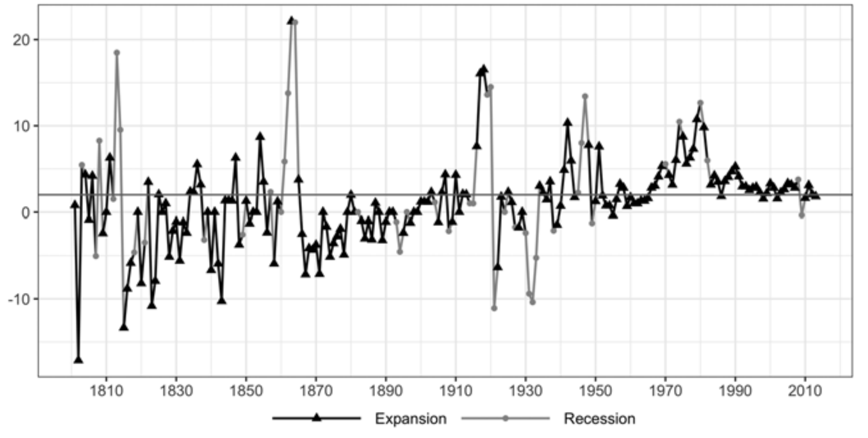
	Inflation	Growth rate
N	213	213
Mean	1.3713	3.6559
S.D.	5.4928	5.3335
Min	-17.1358	-13.9291
Max	22.1161	16.9925
Skewness	0.5057	-0.3137
Kurtosis	2.4409	0.6985
JB	64.3380***	8.3180**
Q(1)	59.5541***	7.6934***
Q(4)	80.8971***	9.4057*
ARCH(1)	45.9068***	13.5161***
ARCH(4)	62.6250***	20.7283***

Notes: In addition to the mean, the standard deviation (S.D.), minimum (min), maximum (max), skewness, and kurtosis statistics, the table reports the Jarque-Bera normality test (JB), the Ljung-Box first [*Q*(1)] and the fourth [*Q*(5] autocorrelation tests, and the first [ARCH(1)] and the fourth [ARCH(5)] order Lagrange multiplier (LM) tests for the autoregressive conditional heteroskedasticity (ARCH). The asterisks ***, ** and * represent significance at the 1%, 5%, and 10% levels, respectively.

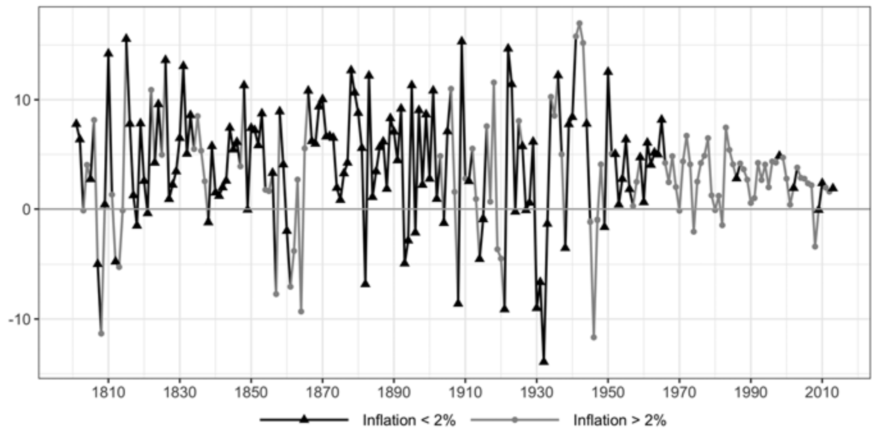
[1] http://oregonstate.edu/cla/polisci/sahr/sahr.

Figure 1. Inflation and GDP growth: 1801-2013

(a) Inflation



(b) Growth



Notes: Part (a) presents the annual inflation rate with recession and expansion periods indicated by different symbols and colors. A light colored horizontal line is draw at the 2% threshold inflation rate. Part (b) presents the GDP growth rate with periods corresponding to less than and greater than the 2% threshold inflation rate market with different colors and symbols.

Figure 1(a) presents the annual inflation rate with recession and expansion dates indicated with gray and symbols. Analogously, Figure 1(b) presents the annual GDP growth rates with the periods corresponding to less than 2% and greater than 2%

inflation rates marked with different colors and symbols. The 2% inflation rate corresponds approximately to the threshold inflation rate estimated nonparametrically in Section IV. Inflation rates above the 2% threshold reduce the GDP growth rate. Figure 1 shows that the inflation threshold and business cycle are not likely to be related, and inflation rates above the threshold corresponds to both expansion and recession periods.

We use a semiparametric model. In the case of the inflation-growth relationship, conditional expectation restrictions might not be satisfied –especially if there are strong feedback loops between inflation and GDP growth. We use an IV approach to control for endogeneity. The semiparametric model allows the data to uncover a more realistic functional form. Our relatively large sample size reduces the possibility of misspecification bias.

The selected IV models are based on the Wu-Hausman *F*-test and the Sargan *J*-test. Wu-Hausman tests the null that the regressors are not correlated with the disturbance term. The *J* statistic tests the null hypothesis that all instruments are exogenous.

In a first stage, we determine which instruments are relevant. At this point, an *F*-test is used to determine whether or not the instruments should enter the first stage regression. Weak instruments imply a small first-stage *F*-test. The auxiliary instrumental variables regressions take the following form:

$$\pi_t = \mu + \theta' z_t + \varepsilon_t , \tag{1}$$

where $\pi_t =$ inflation rate, $z_t = \left[\pi_{t-1}, \pi_{t-2}, \ldots, \pi_{t-p}, g_{t-1}, g_{t-2}, \ldots, g_{t-q}\right]'$ (instrumental variables), g_t = real GDP growth rate and $\varepsilon_t \sim iid\,(0,\sigma^2)$ is the error term.

Then, we estimate the OLS and IV regression models of the following form:

$$g_t = \alpha + \beta \pi_t + \varepsilon_t , \tag{2}$$

and the OLS-lagged model:

$$g_t = \alpha + \beta \pi_{t-1} + \varepsilon_t . \tag{3}$$

Finally, the semiparametric specification can be expressed as follows:

$$g_t = \phi' x_t + f\left(\pi_t\right) + \varepsilon_t , \tag{4}$$

where $f(\pi_t)$ is a nonlinear function and x_t is a set of exogenous variables. We account for the possibility that $E[\varepsilon_t | \pi_t] \neq 0$ by estimating (4) using those models, whose instrument validity is not rejected by the Sargan *J*-test. Following Vaona and Schiavo (2007), we estimate the model in equation (4) using the semiparametric IV estimation approach of Park (2003). The degree of complexity, or optimal data driven method of bandwidth selection, is determined using the least-square cross validation method of Li et al. (2013). A Gaussian kernel is used for all nonparametric and semiparametric models.

IV. Results

Our instruments and exogenous variables only include lagged inflation and lagged GDP. Unfortunately, we do not have enough observations going back until 1802 to control for other variables such as investment or terms of trade. Table 2 and 3, however, report that our instruments are reliable. We estimate nine specifications with different instruments. The specifications in Table 2 indicate that all instruments are adequate (*F*-test is rejected).

The Sargan *J*-statistic from Table 3 show that only models 1, 2, 3, 4, 8 and 9 should be used in the semiparametric model. The coefficients of inflation and lagged inflation on GDP growth are all negative: Inflation reduces economic growth in a linear model. The non-instrumental regressions seem to underestimate the effects of inflation on GDP growth, while the estimates of the IV regressions are all very similar, falling in the interval [-0.274, -0.323].

Table 2. Estimates of the IV auxiliary regressions

	Instruments	R^2	Adj. R^2	$\hat{\sigma}$	*F*	*Q*(20)
Model 1	π_{t-1}	0.3197	0.3164	4.4506	97.2871***	25.1592
Model 2	π_{t-1}, π_{t-2}	0.3214	0.3149	4.4558	48.7916***	25.5407
Model 3	$\pi_{t-1}, \ldots, \pi_{t-3}$	0.3241	0.3142	4.4577	32.7724***	26.9195
Model 4	$\pi_{t-1}, \ldots, \pi_{t-4}$	0.3350	0.3220	4.4325	25.6969***	24.1412
Model 5	π_{t-1}, g_{t-1}	0.3219	0.3153	4.4542	48.9004***	24.3469
Model 6	$\pi_{t-1}, \pi_{t-2}, g_{t-1}$	0.3232	0.3133	4.4608	32.6359***	24.8406
Model 7	$\pi_{t-1}, \pi_{t-2}, g_{t-1}, g_{t-2}$	0.3253	0.3121	4.4647	24.5929***	25.6369
Model 8	$\pi_{t-1}, \ldots, \pi_{t-3}, g_{t-1}, \ldots, g_{t-3}$	0.3281	0.3082	4.4774	16.4424***	26.8569
Model 9	$\pi_{t-1}, \ldots, \pi_{t-4}, g_{t-1}, \ldots, g_{t-4}$	0.3395	0.3131	4.4614	12.8523***	23.3202

Notes: R^2 is the coefficient of determination Adj. R^2 is the adjusted coefficient of determination $\hat{\sigma}$ is the standard error of the regression F is the regression *F* statistic *Q*(20) is the Ljung-Box portmanteau tests of autocorrelation for order up to 20. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Figure 2 plots the relationship between inflation and economic growth. This relationship is nonlinear for all the specifications. The "hump-shaped" relationship almost delivers what looks like a growth maximizing effect. However, it should be noted that the plots generated do not come from any functional form. A functional form that tests for growth maximizing effects of inflation would include a squared term for inflation (with the sign being negative). The results, however, suggest that deflation and high levels of inflation consistently reduces GDP growth across various specifications. The inflation threshold is close to zero and as high as 2 percent.

Table 3. OLS and IV estimates of the linear growth and inflation relationship

	Instruments	Intercept [α]	Inflation [β]	Wu-Hausman *F*-test	Sargan *J*-Test
OLS		3.8468***	-0.1451**		
		(0.3810)	(0.0686)		
OLS lagged		3.8983***	-0.1796***		
		(0.3790)	(0.0681)		
IV Model 1	π_{t-1}	4.0940***	-0.3180***	3.0120*	
		(0.4130)	(0.1230)		
IV Model 2	π_{t-1}, π_{t-2}	4.0930***	-0.3180***	3.0290*	0.001
		(0.4130)	(0.1230)		
IV Model 3	$\pi_{t-1}, \ldots, \pi_{t-3}$	4.1020***	-0.3230***	3.2840*	0.281
		(0.4130)	(0.1220)		
IV Model 4	$\pi_{t-1}, \ldots, \pi_{t-4}$	4.0670***	-0.2990**	2.573	1.495
		(0.4100)	(0.1200)		
IV Model 5	π_{t-1}, g_{t-1}	4.0560***	-0.2920**	2.179	6.7700***
		(0.4110)	(0.1220)		
IV Model 6	$\pi_{t-1}, \pi_{t-2}, g_{t-1}$	4.0590***	-0.2940**	2.264	6.8570**
		(0.4110)	(0.1220)		
IV Model 7	π_{t-1}, π_{t-2}	4.0520***	-0.2880**	2.119	7.1830*
	g_{t-1}, g_{t-2}	(0.4110)	(0.1210)		
IV Model 8	$\pi_{t-1}, \ldots, \pi_{t-3}$,	4.0690***	-0.3010**	2.529	8.953
	$g_{t-1}, \ldots, g_{t-3}$	(0.4110)	(0.1210)		
IV Model 9	$\pi_{t-1}, \ldots, \pi_{t-4}$,	4.0310***	-0.2740**	1.832	10.481
	$g_{t-1}, \ldots, g_{t-4}$	(0.4080)	(0.1190)		

Notes: OLS model is the estimate of $g_t = \alpha + \beta\pi_t + \varepsilon_t$, while OLS-lagged estimates $g_t = \alpha + \beta\pi_{t-1} + \varepsilon_t$ using non-instrumental OLS estimation. IV models are estimated by two stage least squres using the corresponding instruments given in the second column. Wu-Hausman *F* statistic tests for the endogeneity of inflation in Equation (2) given the instruments. Sargan *J* statistic tests for the overidentfying restrictions. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Anything higher than two per cent reduces GDP growth. The nonlinear nature shows that high inflation decreases growth proportionally more compared to low inflation. The slope of Figure 2 is fairly flat for deflation. It is important to note that the confidence bands suggest that the results become insignificant with very high or low inflation (i.e. the growth effect of inflation becomes indiscernible. There exists, however, a corridor or significance that varies between -10 percent and 10 percent of inflation. There exists also a curl at the 20 percent mark. This is simply an artifact of the data - very few data points exist where inflation exceeds 20 percent (only 0.9% of the data is above 20 percent) and this is associated with GDP growth between 2.69 and -9.31 percent, respectively.

While most of the plots suggest that the relationship between inflation and economic growth is "hump-shaped", subplot (b) shows that the relationship between past inflation and current economic growth is monotonic. This is just one incidence where using a misspecified model can lead to strikingly different conclusions. The tests of Table 2 and Table 3 suggest that a more nuanced model is the correct model (i.e. one with a different set of controls).

A parametric model approach is also used to study the evolution of the inflation threshold on GDP growth. Two models are used: time varying parameter (TVP) and smooth transition regression (STR) models.[2] These models can help detect any nonlinearity between inflation and growth and specifically the inflation effect on growth past a certain threshold.

The TVP model is written as:

$$g_t = \alpha_t + \beta_t \pi_t + \varepsilon_t . \quad (5)$$

The Kalman filter produces the parameters in equation (5). The evolution of β_t illustrates the periods where inflation has a negative effect on growth. Figure 3(a) presents the estimates of β_t between 1801 and 2013. Inflation had a negative effect on growth the majority of time, barring two periods. The estimates in Figure 3(a) show that inflation has a negative impact on GDP growth during periods 1801-1832, 1850-1892, and 1950-2013. Inflation did not decrease growth in 1833-1849 (this was part of the industrial revolution age for the U.S. and of inflows of immigrants) and a longer period between 1893 and 1949.

The functional approach of the TVP regression assumes that the relationship between inflation and growth is linear –as such, it is difficult to assess whether an

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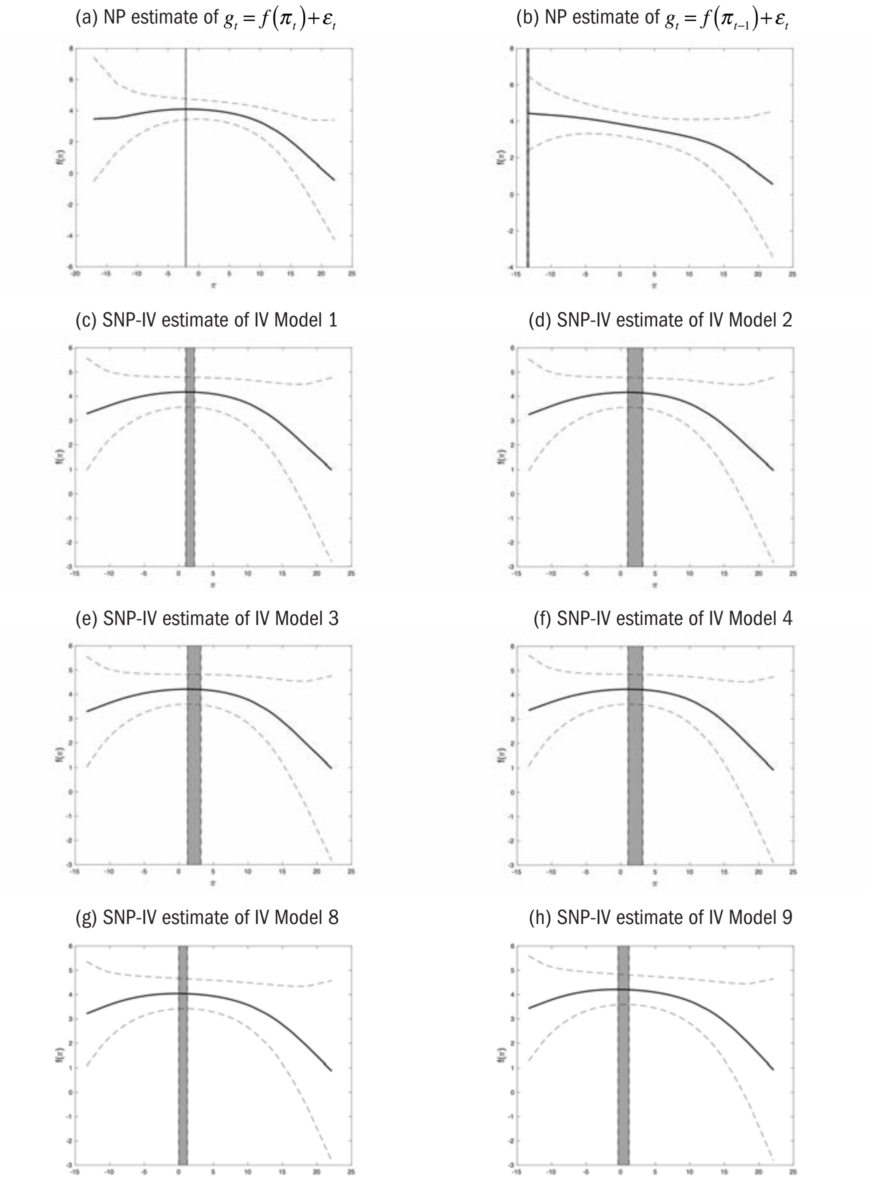
[2] We thank an anonymous reviewer for suggesting the TVP model.

Figure 2. NP and SNP-IV estimates



Notes: Start and end of the maximum of nonparametric curve estimate is marked with vertical dashed lines and sheded with gray color. Upper-end of the maximum of the curve designates the inflation threshold.

inflation threshold exists. A STR model explicitly controls for thresholds and may yield a linear or non-linear result, where nonlinearity is a smooth logistic function over some threshold. We estimate the following STR model:[3]

$$g_t = [\alpha_1 + \beta_1 \pi_t] + [\alpha_2 + \beta_2 \pi_t] G(\pi_t; \gamma, c) + \varepsilon_t, \tag{6}$$

where c is the threshold inflation rate, $G(\pi_t;\gamma,c) \in (0,1)$ is a continuous function and allows a smooth transition between the below threshold regime ($\pi_t \leq c$) and the above threshold regime ($\pi_t > c$), and $\gamma > 0$ is the slope parameter that controls the speed of adjustment from one regime to the other. In our application $G(\pi_t;\gamma,c)$ is specified with a logistic function and takes the following form:

$$G(\pi_t;\gamma,c) = \left[1 + \exp\{-\gamma(\pi_t - c)\}\right]^{-1}. \tag{7}$$

In order to be consistent with the nonparametric estimate of the inflation threshold we set $c = 2\%$ in equation (7) and estimate the remaining parameters conditional on the pre-specified threshold. Estimates of the logistic STR model are shown in Table 4. The effect of inflation on GDP growth is positive but insignificant in the below threshold inflation regime ($\pi_t \leq 2\%$) while it is negative and significant in the above threshold inflation regime ($\pi_t > 2\%$). This result is in perfect agreement with our finding from the nonparametric analysis, where the estimated curve between growth and inflation is flat up to 2% for inflation, but significantly negatively sloped above the 2% inflation level. Figure 3(b) presents the estimates of the transition function given in equation (7). The shaded region in Figure 3(b) corresponds to the regime with above threshold inflation periods, i.e., $\pi_t > 2\%$. We also shade the same periods in Figure 3(a) to compare the STR and TVP estimates. The periods where the inflation has negative impact on growth correspond to periods 1803-1920, 1941-1950, and 1965-2013. These periods closely correspond to the negative impact estimates from the TVP model, showing that both the TVP and STR uncover similar results. Figure 3(c) is a scatterplot of the estimates of the $G(\pi_t;\gamma,c)$ in equation (7) against the threshold variable inflation. The shape of the transition function in Figure 3(c) show that the transition between the regimes is moderately slow as indicated by the estimate of γ, which 3.8543 as seen from Table 4, and more importantly points to nonlinearity.

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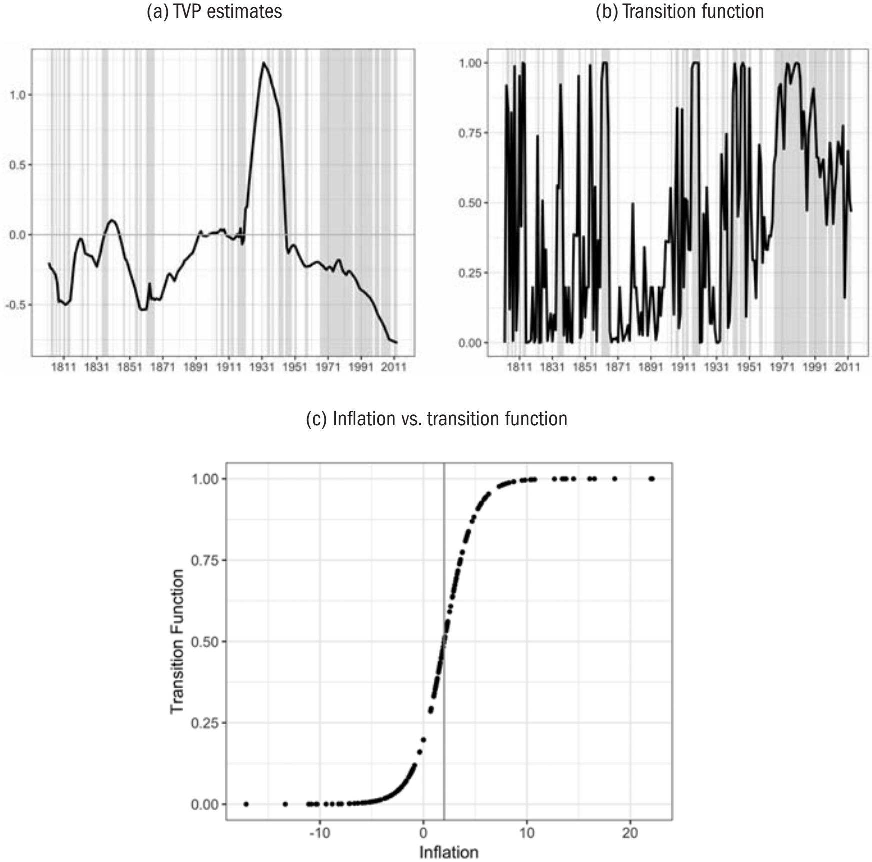
[3] See Teräsvirta and Anderson (1992) and Granger and Teräsvirta (1993) for the details of the STR model.

Figure 3. Time varying parameter and threshold regression estimates



Notes: Part (a) presents the estimates of the slope parameter β_t from a time varying parameter (TVP) model $g_t = \alpha_t + \beta_t \pi_t + \varepsilon_t$ .Part (b) presents the transition function $G(\pi_t;\gamma,c)$ of the two-regime smooth transition regression (STR) model $g_t = [\alpha_1 + \beta_1 \pi_t] + [\alpha_1 + \beta_1 \pi_t] G(\pi_t;\gamma,c) + \varepsilon_t$ with the threshold inflation c set to 2%. Part (c) presents the scatter plot of the transition function $G(\pi_t;\gamma,c)$ against the switch variable inflation (π_t). A vertical line at 2% threshold inflation is drawn on Part (c). The shaded regions in Parts (a) and (b) corresponds to the periods where $G(\pi_t;\gamma,c) > 0.50$, the case where the inflation is above the threshold level 2%.

The effects of deflation on growth should be analysed with caution. The adverse economic effects of the ZLB, such as the inability of monetary policy to stimulate aggregate demand in recessions (Krugman 1998), might outweigh the growth benefits of deflation. It would seem prudent for the FED to keep inflation expectations anchored at a very low level, given the consequences of the ZLB and balancing it with the economic effects of higher inflation; or in the model specification of Billi (2011) –commitment seems to be the appropriate policy response. An analysis of the economic benefits and adverse effects of deflation is beyond the scope of this

Table 4. Estimates of the logistic STR model

Parameter	Estimate	Standard error
Low regime parameters ($\pi_t \leq 2\%$)		
α_1	4.2830***	1.0650
β_1	0.1134	0.1558
High regime parameters ($\pi_t > 2\%$)		
α_2	4.8847**	2.4271
β_2	-0.3573**	0.1734
Nonlinear parameters		
γ	3.8543	2.7383
c	2.0000	–

Notes: Table reports the estimates of the STR model $g_t = [\alpha_1 + \beta_1\pi_t] + [\alpha_1 + \beta_1\pi_t]G(\pi_t;\gamma,c) + \varepsilon_t$ given in equation (6) with the threshold inflation c set to 2%. The transition function G(ptg,c) is specified as a logistic function given in equation (7). *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

paper, but offers an interesting avenue for further study. The results, in this study, however, suggest that deflation, although not as strong as high inflation, also subtracts from economic growth.

The policy implications of these results are also quite difficult to advance. One might be tempted to gauge from the results that inflation much higher or lower than 2 percent permanently reduces growth. However, the empirical results rely on growth rates (i.e., they are stationary) and inference on the long-run is thus not possible. The result from the welfare literature on inflation mentioned earlier suggests that high inflation may permanently reduce economic growth. The results do not control for inflation expectations. As a consequence no inference can be made regarding the role of inflation expectations on economic growth or how agents substitute one type of asset class for another because of inflation expectations. We argue that the long time series data, and the implicit relationship between growth and inflation in this data, controls for changes in expectations. The paper does not advance a position on what the FED target for inflation should be. It only describes the relationship between inflation and growth and suggests that inflation roughly equal to 2 percent does not subtract from growth.

V. Conclusion

The effects of inflation on economic growth for the United States are studied using a novel time series dataset that spans over a century. A semiparametric instrumental variables method controls for endogeneity and allows the data to uncover results without imposing any functional forms or restrictions. The results consistently suggest that the inflation-growth relationship is nonlinear, with a threshold of about two percent. Two additional parametric specifications confirm the results. The hump shaped relationship implies that high inflation reduces economic growth proportionally more relative to low inflation. An interesting finding of this paper is that it shows that deflation can also reduce growth, contrary to some research findings. This paper does not suggest that the Fed should follow a deflation policy –the obvious consequence being that monetary policy becomes ineffective at the zero lower bound. This result does however warrant further investigation of a comparison of the economic benefits of deflation and the adverse effects of the zero lower bound on growth.

References

Billi, Roberto M (2011). Optimal inflation for the U.S. economy. *American Economic Journal:Macroeconomics* 3: 29–52.

Barro, Robert J (1995). Inflation and economic growth. Working Paper 5326. Cambride, MA, NBER.

Bruno Michael, and William Easterly (1998). Inflation crises and long-run growth. *Journal of Monetary Economics* 41:3–26.

Budekin, Richard C.K., Arthur T. Denzau, Manfred W. Keil, Thitithep Sitthiyot, and Thomas D. Willett (2004). When does inflation hurt economic growth? Different nonlinearities for different economies. *Journal of Macroeconomics* 26: 519–532.

Chari, V.V., Larry E. Jones, and Rodolfo E. Manuelli (1995). The growth effects of monetary policy. *Quarterly Review* 19: 18–32. Federal Reserve Bank of Minneapolis.

Fischer, Stanley (1981). Towards an understanding of the costs of inflation: II. *Carnegie-Rochester Conference Series on Public Policy* 15: 5–41.

Fischer, Stanley (1993). The role of macroeconomic factors in growth. Working Paper 4565. Cambridge, MA, NBER.

Granger, Clive W. J. and Timo Teräsvirta (1993). *Modelling nonlinear economic relationships*. Oxford University Press, Oxford.

Ireland, Peter N. (2009). On the welfare cost of inflation and the recent behavior of money demand. *American Economic Review* 99: 1040-1052.

Khan, Moshin S.. and Abdelhak S. Senhadji (2001). Threshold effects in the relationship between inflation and growth. *IMF Staff Papers* 48: 1–21.

Krugman, Paul.R. (1998). It's baaack: Japan's slump and the return of the liquidity trap. *Brookings Papers on Economic Activity* 29: 137–206.

Li, Qi, Juan Lin, and Jeffrey S. Racine (2013). Optimal bandwidth selection for nonparametric conditional distribution and quantile functions. *Journal of Business and Economic Statistics* 31: 57–65.

Miller, Stephen M., Luis Filipe Martins, and Rangan Gupta (2014). A time-varying approach of the U.S. welfare cost of inflation. Department of Economics, University of Connecticut, Working Paper No. 2014-11.

Park, Sanjin (2003). Semiparametric instrumental variable estimation. *Journal of Econometrics* 112: 381–399.

Reifschneider, David, and John C. Williams (2000). Three lessons for monetary policy in a low-inflation era. *Journal of Money, Credit and Banking* 32:936–966.

Roubini, Nouriel, and Xavier Sala-i-Martin (1992). A growth model of inflation, tax evasion, and financial repression. National Bureau of Economic Research. Working Paper 4062. Cambridge, MA, NBER.

Rousseau, Peter L., and Paul Wachtel (2001). Inflation, financial development and growth. In T. Negishi, R. Ramachandran, K. Mino, editors, *Economic theory, dynamics and markets: Essays in honor of Ryuzo Sato*. Kluwer. Available at SSRN:http://ssrn.com/abstract=252929.

Serletis, Apostolos, and Kazem Yavari (2004). The welfare cost of inflation in Canada and the United States. *Economics Letter* 84: 199–204.

Teräsvirta, Timo, and Heather M. Anderson (1992). Characterizing nonlinearities in business cycles using smooth transition autoregressive models. *Journal of Applied Econometrics* 7: S119–S136.

Vaona, Andrea, and Stefano Schiavo (2007). Nonparametric and semiparametric evidence on the long-run effects of inflation on growth. *Economics Letters* 94: 452–458.

Vaona, Andrea (2012). Inflation and growth in the long run: A new Keynesian theory and further semiparametric evidence. *Macroeconomic Dynamics* 16: 94–132.