Did Sunspot Forces Cause the Roaring Twenties? *

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Preliminary draft: November 7, 2005 (comments welcome)

Abstract

We apply a dynamic general equilibrium model to the period of the U.S. Roaring Twenties. In particular, we examine a modification of the real business cycle (RBC) model in which the possibility of indeterminacy of equilibria arises. In other words, in addition to technology shocks, agents' self-fulfilling expectations can serve as a primary impulse behind fluctuations. We estimate both shocks using U.S. data. The sunspot, or belief shock, is calculated using asset returns. We then examine the behaviors of output and consumption when fluctuations are driven by either or both shocks. We find that the model economy in which only sunspot shocks matter best describes the 1920s.

1 Introduction

The boom of the 1990s has inspired interest among neoclassical economists in studying unique episodes in the history of the US economy. Of interest to us is the literature on the Great Depression, led by Cole and Ohanian (1999, 2001) and including Bordo, Erceg and Evans (2000), and Ohanian (2001), among others. Harrison and Weder (HW 2005), in particular assess the possibility that a neoclassical model in which

* *Keywords*: Roaring Twenties, Sunspots, Dynamic General Equilibrium. *JEL Classifications*: **E32, N12**

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self-fulfilling beliefs drive business cycles might explain the Great Depression. They provide evidence that extrinsic pessimism starting in 1930 turned what might have been a recession into the Great Depression. Here we carry out a similar analysis, this time studying the decade of the Roaring Twenties.

In particular, we examine a modification of the real business cycle model in which the possibility of indeterminacy of equilibria arises.[1] The indeterminacy arises when, in the presence of relatively low increasing returns to scale in production and variable capacity utilization, changes in agents' expectations are self-fulfilling and therefore serve as a primary impulse behind fluctuations. These sunspot shocks are extrinsic, or nonfundamental and the mechanism by which they work is as follows. In the presence of increasing returns to scale and upon optimistic expectations about the future return to capital, the household will increase today's investment and lower today's consumption. This shifts out the labor supply curve, increasing output and therefore capital utilization. Labor therefore increases even more as a consequence of an outward shift of the equilibrium labor demand schedule. Accordingly, the household will find itself with an augmented future capital stock and higher output; and its initial optimistic expectations are self-fulfilled.

While the goal of assessing the relevance of beliefs remains the same, our methodology is different than in HW. In that paper, an interest rate spread, which widens when a recession is expected, serves as a proxy for confidence. The authors then construct a vector autoregression model (VAR) in which the residual from a regression of the spread on fundamentals is taken to measure nonfundamental confidence, or the sunspot shock. This series is then fed into the model. Here we examine the idea that belief shocks that drive the economy also drive asset returns. We follow the work of Salyer and Sheffrin (SS, 1998) and identify the belief shocks in the model by adding a financial market. Since financial markets are believed to be driven in part by expectations, using realized asset returns may help us to better understand and isolate the source of the belief shocks. We use US data to compute implied values of the belief shock. We then feed these into the model and examine the ability of the belief-driven series to replicate those in the data. In particular, we compare model output and consumption to these series in the data. Our sample is annual over the period 1889-1953. We use data on output from Kendrick (1961), and on real consumption (nondurables and services) and the real gross stock market return (S&P 500) from Shiller (http://www.econ.yale.edu/~shiller/data.htm). The analysis also requires data on the capital stock and employment (total hours worked), which is also from Kendrick (1961).

Our results indicate that the sunspot explanation can account well for the growth in output during the Roaring Twenties. We provide possible explanations for the model's successes and failures, and alternative methods of evaluating the Roaring Twenties from this perspective later in the paper. The rest of this paper proceeds as follows. In section 2 we discuss the model and the sunspot shocks. In section 3 we

[1] See Benhabib and Farmer (1999) for a comprehensive review of such models.

briefly discuss the Roaring Twenties. Section 4 summarizes our results and Section 5 concludes.

2 The Model

This section presents the theoretical model, discusses the calibration, and reports on qualitative dynamics. The economy builds on the standard real business cycle (RBC) model, from which there are two departures: the pace of capital utilization is endogenously set and technology displays external economies of scale.[2] Taken together, these departures can lead to equilibria that are not uniquely determined by preferences and technology. That is, the artificial economy may be driven by non-fundamental shocks to expectations.

2.1 Firms

Output is produced by competitive firms who have access to an increasing returns to scale technology given by

$$y_{i,t} = z_t A_t^{\gamma} (u_{i,t} k_{i,t})^{\alpha} l_{i,t}^{1-\alpha} \qquad A_t = (u_t k_t)^{\alpha} l_t^{1-\alpha}, \quad 0 < \alpha < 1. \tag{1}$$

Here A_t represents an aggregate externality which is a function of the average economy-wide levels of labor, l_t, and effective capital inputs, $u_t k_t$. Firms rent the services from labor, $l_{i,t}$, and capital, $k_{i,t}$, from the household at the competitive rental rates w_t and r_t. The index of the use of capital, u_t, is determined by the households, and taken as a given by the firms. z_t is the state of technological knowledge, or total factor productivity (TFP), which is determined outside the model. It follows the first-order autoregressive process

$$\ln z_t = (1-\rho)\ln z + \rho \ln z_{t-1} + \omega_t \qquad\qquad 0 < \rho < 1. \tag{2}$$

The shocks to technology, ω_t, are uncorrelated at all leads and lags and uncorrelated with z_{t-j} $\forall j > 0$. They are the part of z_t that cannot be predicted based on past values of the variables of the model. Each competitor's profit maximization is given by the static problem

$$\max_{l_{i,t}, u_t k_{i,t}} y_{i,t} - w_t l_{i,t} - r_t u_t k_{i,t} \qquad\qquad \text{s.t. } (1).$$

The factor demands of firm i are

$$w_t = (1-\alpha) z_t (u_t k_{i,t})^{\alpha} l_{i,t}^{-\alpha} \qquad \text{and} \qquad r_t = \alpha z_t (u_t k_{i,t})^{\alpha-1} l_{i,t}^{(1-\alpha)}. \tag{3}$$

[2] The models of Greenwood, Hercowitz and Huffman (1988) and Wen (1998) feature similar attributes.

That is, firms rent effective capital units, i.e. $u_t k_{i,t}$. The reason is the following. Technology displays a nonconvexity if the usual commodity point is employed, so an alternative commodity is needed. Our approach is to assume that firms demand effective capital units. Phrased alternatively, from the firm's point of view, output can be increased by running existing machines more intensely or by putting into operation additional machines; the decision is made by the households who own the capital stock and who can decide on the utilization rate.

2.2 Households

All intertemporal decisions are administered by the household sector. Households supply labor to and purchase output from the firms. The household's preferences are ordered by

$$U = E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t) \qquad 0 < \beta < 1 \tag{4}$$

where c_t and β stand for consumption and the discount factor. The period utility function is assumed to have the form

$$u(c_t, l_t) = \eta \log c_t + (1-\eta) l_t \qquad 0 < \eta < 1$$

and the households face the constraints:

$$c_t + x_t = y = r_t k_t + w_t l_t \tag{5}$$

$$k_{t+1} = (1-\delta_t) k_t + x_t; \qquad \delta_t = \frac{1}{\theta} u_t^{\theta}; \qquad \theta > 1$$

Here x_t denotes investment and δ_t is the depreciation rate. The fact that labor enters linearly into the utility function follows the assumption that labor is indivisible, utility is separable in consumption and in leisure and agents trade employment lotteries. E_t is the expectations operator, conditional on all information available in periods t and earlier. Depreciation is an increasing convex function of utilization. Higher utilization causes faster depreciation because of wear and tear on the capital stock. Factor prices (and profit income) are taken as given by the household. The maximization of (4) subject to (5) yields the first-order conditions

$$\frac{\eta}{1-\eta} = \frac{w_t}{c_t} \tag{6}$$

$$\frac{1}{c_t} = E_t \frac{\beta}{c_{t+1}} \left(r_{t+1} u_{t+1} + 1 - \frac{1}{\theta} u_{t+1}^{\theta} \right) \tag{7}$$

$$u_t^{\theta-1} = r_t. \tag{8}$$

In addition, the budget constraint

$$k_{t+1} = (1-\delta_t) k_t + y_t - c_t$$

and the usual transversality condition – given the initial stock of capital, $k(0) > 0$ – must hold. Equation (6) describes the consumption-leisure trade-off, (7) is the intertemporal Euler equation. (8) characterizes the efficient level of capital utilization. It states that capital should be utilized at a rate which sets the marginal user costs equal to the marginal benefit of capital services.

2.3 Equilibrium and Dynamics

We focus on symmetric perfect-foresight equilibria for which the resource constraint is:

$$c_t + x_t = y_t = (u_t k_t)^{\alpha(1+\gamma)} l_t^{(1-\alpha)(1+\gamma)}.$$

We have $k_{i,t} = k_t$, $l_{i,t} = l_t$, and $y_{i,t} = y_t$. The first-order conditions with respect to capital utilization and investment become

$$u_t^\theta = \alpha \frac{y_t}{k_t}$$

and

$$\frac{1}{c_t} = E_t \frac{\beta}{c_{t+1}} \left(\alpha \frac{y_{t+1}}{k_{t+1}} + 1 - \frac{1}{\theta} u_{t+1}^\theta \right) \tag{9}$$

and, consequently, the commodity point selection does not change the usual forms of these Euler equations.[3] It is straightforward to show that our model possesses a unique interior steady state.

We take log-linear approximations to the equilibrium conditions to obtain the following dynamic system:

$$\begin{bmatrix} \widehat{c}_{t+1} \\ \widehat{k}_{t+1} \\ \widehat{z}_{t+1} \end{bmatrix} = \mathbf{Q}_1 \begin{bmatrix} \widehat{c}_t \\ \widehat{k}_t \\ \widehat{z}_t \end{bmatrix} + \mathbf{Q}_2 \begin{bmatrix} \widehat{\varepsilon}_{t+1} \\ \widehat{w}_{t+1} \end{bmatrix} \tag{10}$$

where hat variables denote percent deviations from their steady-state values; and $\mathbf{Q}_1$ is the 3 X 3 Jacobian matrix of partial derivatives of the transformed dynamic system evaluated at the steady state. Here $\widehat{\varepsilon}_{t+1}$ is the expectational error, or belief shock, which is by definition serially uncorrelated and mean zero. Mathematically, indeterminacy requires then that all eigenvalues of $\mathbf{Q}_1$ are inside the unit circle. In our model calibration, indeterminacy arises for external effects exceeding 1.105. Since all variables have now been log-linearized, we can express the rest of them each as a

[3] See for example Greenwood et al. (1998) or Wen (1998).

linear combination of consumption, capital and TFP:

$$\begin{bmatrix} \widehat{y}_{t+1} \\ \widehat{u}_{t+1} \\ \widehat{l}_{t+1} \\ \widehat{R}_{t+1} \\ \widehat{w}_{t+1} \\ \widehat{x}_{t+1} \end{bmatrix} = \mathbf{J} \begin{bmatrix} \widehat{c}_{t+1} \\ \widehat{k}_{t+1} \\ \widehat{z}_{t+1} \end{bmatrix}, \tag{11}$$

where $\mathbf{J}$ is a matrix determined by the log-linearization.

Next we calibrate the model using parameter values that are typically found in the real business cycle and indeterminacy literatures. The time period is considered to be a year. The capital share, α, is 30 percent and the steady state rate of depreciation is 10 percent. The discount factor, β, is set at 0.97 which implies an annual steady state return of about 3%. The first order condition with respect to capital utilization together with the euler equation imply that $\theta = 1.309$**.** Increasing returns must also be calibrated. Bernanke and Parkinson (1991) and Burns (1936) find evidence of significant increasing returns during the interwar years. We set $\gamma = 0.15$, implying returns to scale of 1.15, which cannot be rejected by Basu and Fernald (1997). We compute model-consistent utilization from the first-order condition

$$u_t = \left(0.3\frac{y_t}{k_t}\right)^{1/1.309}.$$

Given this calibration, total factor productivity is computed, accounting for increasing returns, by

$$z_t = \frac{y_t}{(u_t k_t)^{0.345} l_t^{0.805}}.$$

We linearly detrend z_t by regressing it on a constant and a time trend. We find that this resulting series is well described by a first order autoregressive process with $\rho = 0.763$.

2.4 Sunspot shocks

The method of deriving the sunspot shocks is best understood as analogous to computing a Solow residual to identify the technology shock. SS conceive of the relevant return in the model as being the return on equity, and the sunspot shock is identified by linearizing the euler equation (9):

$$\frac{1}{c_t} = E_t \frac{\beta}{c_{t+1}} \left(R_{t+1}\right); \qquad R_{t+1} = \alpha \frac{y_{t+1}}{k_{t+1}} + 1 - \delta_{t+1}$$

where R_{t+1} denotes the gross return on equity. Then, denoting linearized variables with hats, we can write:

$$\widehat{c}_t = E_t \widehat{c}_{t+1} - E_t \widehat{R}_{t+1} \tag{12}$$

In our calibrated model, using (10),

$$\widehat{c}_{t+1} = 1.178\widehat{c}_t - 0.061\widehat{k}_t - .018\widehat{z}_t - 1.545\widehat{\varepsilon}_{t+1} - .676\widehat{w}_{t+1} \tag{13}$$

so that

$$E_t\widehat{c}_{t+1} = 1.178\widehat{c}_t - 0.061\widehat{k}_t - .018\widehat{z}_t. \tag{14}$$

Setting

$$\widehat{R}_{t+1} = \alpha_0\widehat{c}_t + \alpha_1\widehat{k}_t + \alpha_2\widehat{z}_t + \alpha_3\widehat{\varepsilon}_{t+1} + \alpha_4\widehat{w}_{t+1}, \tag{15}$$

from (11) so that

$$E_t\widehat{R}_{t+1} = \alpha_0\widehat{c}_t + \alpha_1\widehat{k}_t + \alpha_2\widehat{z}_t, \tag{16}$$

we can substitute (14) and (16) into (12) to solve $\alpha_0 = 0.178$, $\alpha_1 = 0.061$ and $\alpha_2 = -.018$. Then, using (13) to solve for $\widehat{k}_t$ and substituting into (15) we have:

$$(\alpha_3 + 1.545)\widehat{\varepsilon}_{t+1} = \widehat{c}_t + \widehat{R}_{t+1} - \widehat{c}_{t+1} - (\alpha_4 + .676)\widehat{w}_{t+1}. \tag{17}$$

We can use (11) to solve for the value of α_3, by substituting in our calibration, and using (10). We have $\alpha_3 = -.545$ so that (17) becomes:

$$\widehat{\varepsilon}_{t+1} = \widehat{c}_t + \widehat{R}_{t+1} - \widehat{c}_{t+1} - (\alpha_4 + .676)\widehat{w}_{t+1}. \tag{18}$$

3 The Roaring Twenties

The 1920s is characterized by DeLong (1997) as an era of mass production, led by Henry Ford whose innovations included not only the hiring of unskilled workers on a capital-intensive, very productive assembly line, but also the paying of high wages in order to keep his workers. According to DeLong, in 1913 workers were paid a little less than $2.00 a day, and Ford's turnover rate was 370%. By 1915, with a wage of $5.00/day, the turnover rate fell to 16%. DeLong also reports that motor vehicle production rose from 485,000 in 1913 to 4,359,000 in 1928, and back down to 3,971,000 in 1935. Along with mass production led by Ford came the birth of product differentiation and advertising, led by Alfred Sloan, the president of GM from 1923-1941 (digitalhistory.com). And lastly was the creation of installment credit. All of this naturally led to a mass consumption of not only cars, but other durable goods to which mass production spread. Most notable is the telephone, electricity and consumer appliances.

However, the trends in aggregate variables do not lend themselves to interpreting this decade as special, in the way we think of the 1990s as such. In particular, the following Table summarizes the average annual growth experiences in per capita output and consumption over the decades in our sample.

Table 1		
Decade	Output growth	Consumption growth
1890-1899	2.289	2.159
1900-1909	2.235	2.319
1910-1919	1.264	0.527
1920-1929	2.134	2.982
1930-1939	-0.500	0.251
1940-1949	2.650	2.660

Figures 1 and 2 also display this information. In Figures 1a and 1b we plot the natural log of and HP-filtered output while Figure 2 displays the natural log of consumption. While consumption growth in the 1920s stands out, three other decades surpass the 1920s in output growth. Three recessions, each lasting over a year, from 1920:1 to 1921:3, 1923:2 to 1924:3 and 1929:3 to 1927:4, contributed to the lack of luster in growth of output. However, the average growth rate from 1922 to 1929 was 3.49%; and as seen in Figure 1b, HP-filtered output shows strong growth starting in 1922.

Using our calculation of TFP from Section 2.3 above, the following table reports the respective figures per decade.

Table 2		
Decade	Output growth	TFP Growth
1890-1899	2.289	0.919
1900-1909	2.235	0.896
1910-1919	1.264	1.113
1920-1929	2.134	1.589
1930-1939	-0.500	1.405
1940-1949	2.65	1.539

TFP growth was the highest during the 1920s – however no clear pattern emerges. Decades with high output growth experienced low TFP growth rates (for example, the 1890s) and decades with low output growth experienced high TFP growth rates (for example, the 1930s[4]). Figure 3 plots TFP shocks for the considered period. The twenties are characterized by low volatility. The new inventions appear not to show up in large innovations to TFP. However, their average over this period is positive.

The current paper looks into non-fundamental sources of the roaring twenties. Ginzberg (2004) offers such evidence of optimism on the parts of consumers during the 1920s. Relevant for us, he also observes that much of this optimism was not driven by fundamentals. He points to the "high wage doctrine" and the belief in the

[4] See Field (2003) for evidence.

continuing stability of prices as the drivers of this optimism. The former refers to the belief that the prevailing high wages would continue, and were good for the economy. He observes that:

> "...the conviction became widespread that the prevailing prosperity could long continue...Depressions were perhaps a thing of the past...Today it is clear that the contemporary evaluation of the twenties was fundamentally incorrect, but it is not clear why contemporaries held firmly to the belief in economic balance...the populace must have been favorably predisposed to the gospel of enduring prosperity." (p 11)

Not only were contemporaries persistent in holding to their beliefs, but Ginzberg argues that "Doubtful was... the doctrine of high wages that sought to explain the dynamics of the era by virtues inherent in rising wage rates. The data were sparse, and the logic was weak." (p 132) and "Under the sway of the doctrine, optimism ran rampant; fundamental contradictions were politely denied." (p 68). These quotes summarize well our view of the Roaring Twenties: nonfundamental optimism drove consumer demand.

4 Results

In this section, we seek to explain the Roaring Twenties with our model and the calculated sunspot and technology shocks. We use (18) to solve for the belief shock using US data on R, c, and w. As in SS, the value of α_4 is chosen so that the sunspot shock, $\widehat{\varepsilon}$, and the innovation to technology, $\widehat{w}$, are orthogonal. As evidenced in Table 3, the sunspot shocks are serially uncorrelated at every lag.

Table 3
Breusch-Godfrey Serial Correlation LM Test

Lags	F-statistic	p-value
1	0.579458	0.575538
2	0.181694	0.178224
3	0.230463	0.225636
4	0.353269	0.344884

Figure 4 shows our calculated sunspot shocks over the sample. We observe optimistic shocks to expectations throughout the Roaring Twenties, except for in 1923, when there was a recession. Through no other decade were expectations consistently optimistic.

Next, the calculated shocks are fed into the linearized version of the theoretical model. For our *baseline simulations*, we use only sunspot shocks. We do this for two reasons. First, we wish to isolate the effects of the belief shocks. Second, we have freedom in choosing the variance of the shocks. To prevent overfitting using both shocks, we therefore use only one, and match the variance of output in the data. Below we present results using only technology shocks, and then using both shocks.

In Figure 5 we display data on detrended output along with simulated model data. The 11% growth in model output more than explains the 8% growth in the data. Looking at HP-filtered data in Figure 6, both data and model demonstrate growth of about 15%. In Figure 7 we display detrended consumption. Consumption in the data grew by 11.5%, and only by 2.4% in our model. This result is expected, given the inclusion of variable capacity utilization in the model. Variable utilization allow for an extra margin of adjustment, allowing risk-averse agents extremely smooth consumption. (See Wen, 1998, and Benhabib and Wen, 2003).

The inclusion of increasing returns in our model aids in replication of the overall experience of the 1920s. The series of positive belief shocks are propagated over time because the presence of increasing returns to scale encourages "bunching" of periods of high output when agents are optimistic. That is, once the economy is in state of high economic activity, agents are persuaded to take advantage of high returns to scale, and output can stay persistently high (mathematically, the result of the complex and persistent roots of $\mathbf{Q}_1$). Thus, identified sunspots coupled with endogenous persistence constitute important ingredients of a theory of the Roaring Twenties.

In Figures 8 and 9 we display results using only TFP shocks, and both shocks. In Figure 8, output in the model grows by a huge 20% while in the data the growth is only 8%. Here the persistence of shocks in the model is arguably too much. In Figure 9 the same problem emerges, output in the data grew by only 7.2% but in the model 28%. We conclude that a model in which persistent technology shocks and increasing returns to scale drive the fluctuations during the 1920s is not appropriate. On the other hand, the persistence provided by increasing returns to scale combined with i.i.d. sunspot shocks representing beliefs results in a model that can well explain this period.

5 Conclusion

In this paper we have examined the hypothesis that nonfundamental optimism contributed to the Roaring Twenties. Historical vidence suggests that this is the case, and our test involves the use of a theoretical model in which self-fulfilling expectations result with empirically plausible returns to scale. Our results do suggest support for the idea that the fluctuations of the 1920s were belief-driven. In particular, using real stock market returns to derive these beliefs has proven to be useful.

We have several ideas for further extending this analysis. Since the decade was characterized by both recessions and expansions, the analysis here should perhaps be different from that of the Great Depression in that replication of aggregate variables might not be the appropriate test. Since the 1920s was also in particular characterized by increases in durable good production and spending, a better test might be to use a model with two sectors: durables and non-durables, such as Weder (1998), and to examine its ability to replicate output and its components in the two sectors separately.

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Figure 1a: Natural Log of Real GNP per capita

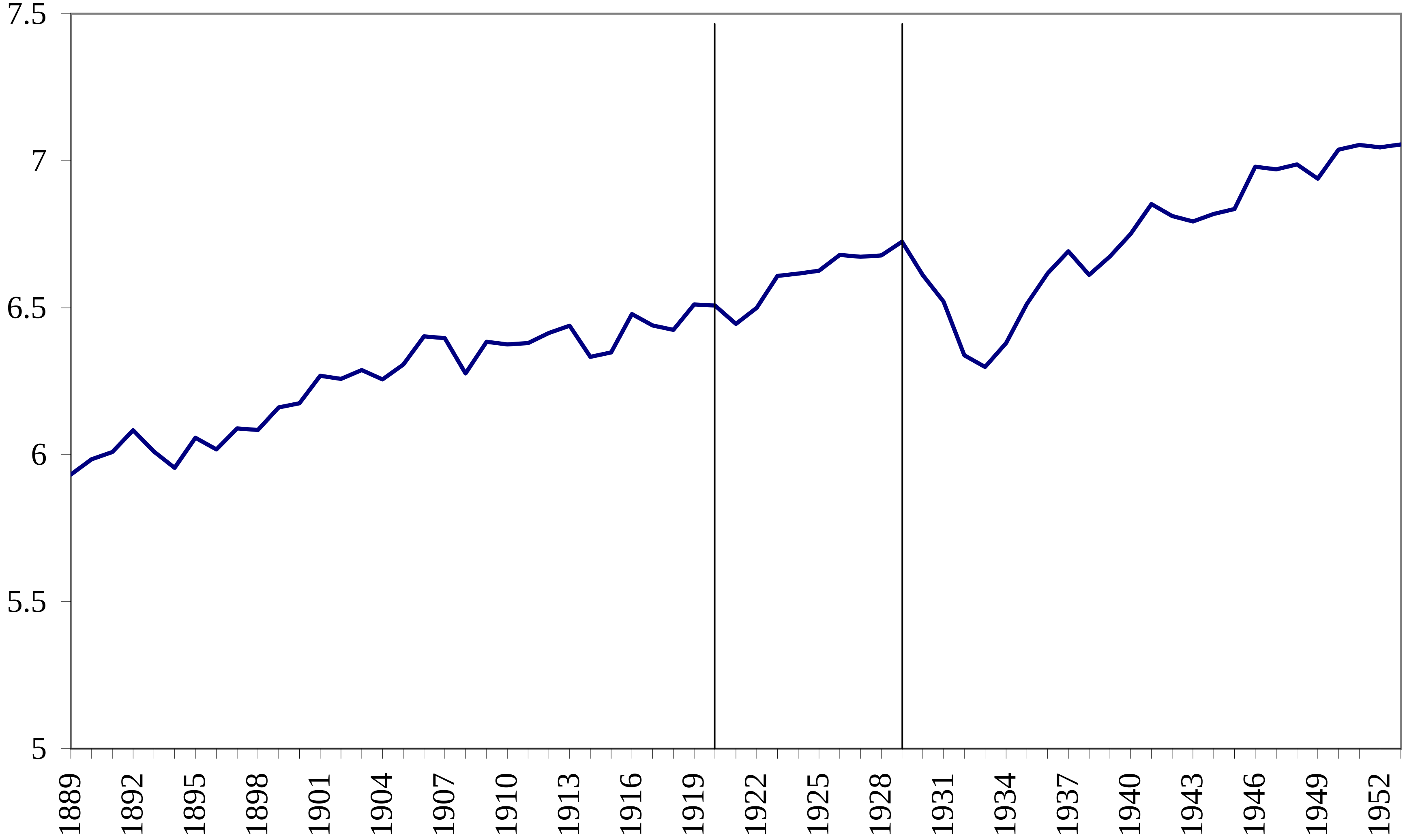

Figure 1b: HP-Filtered Real GNP per capita

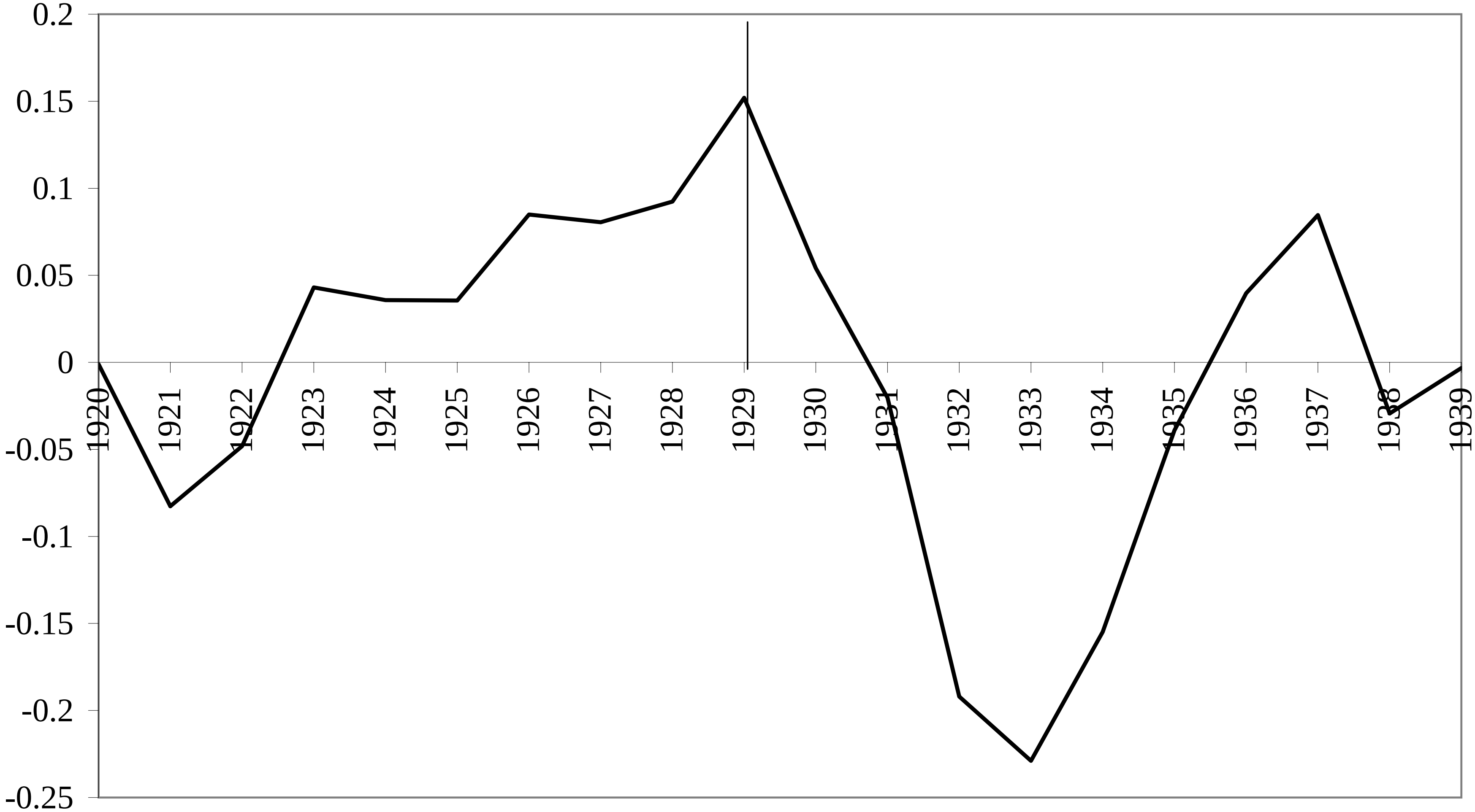

Figure 2: Natural Log of Real Consumption per capita

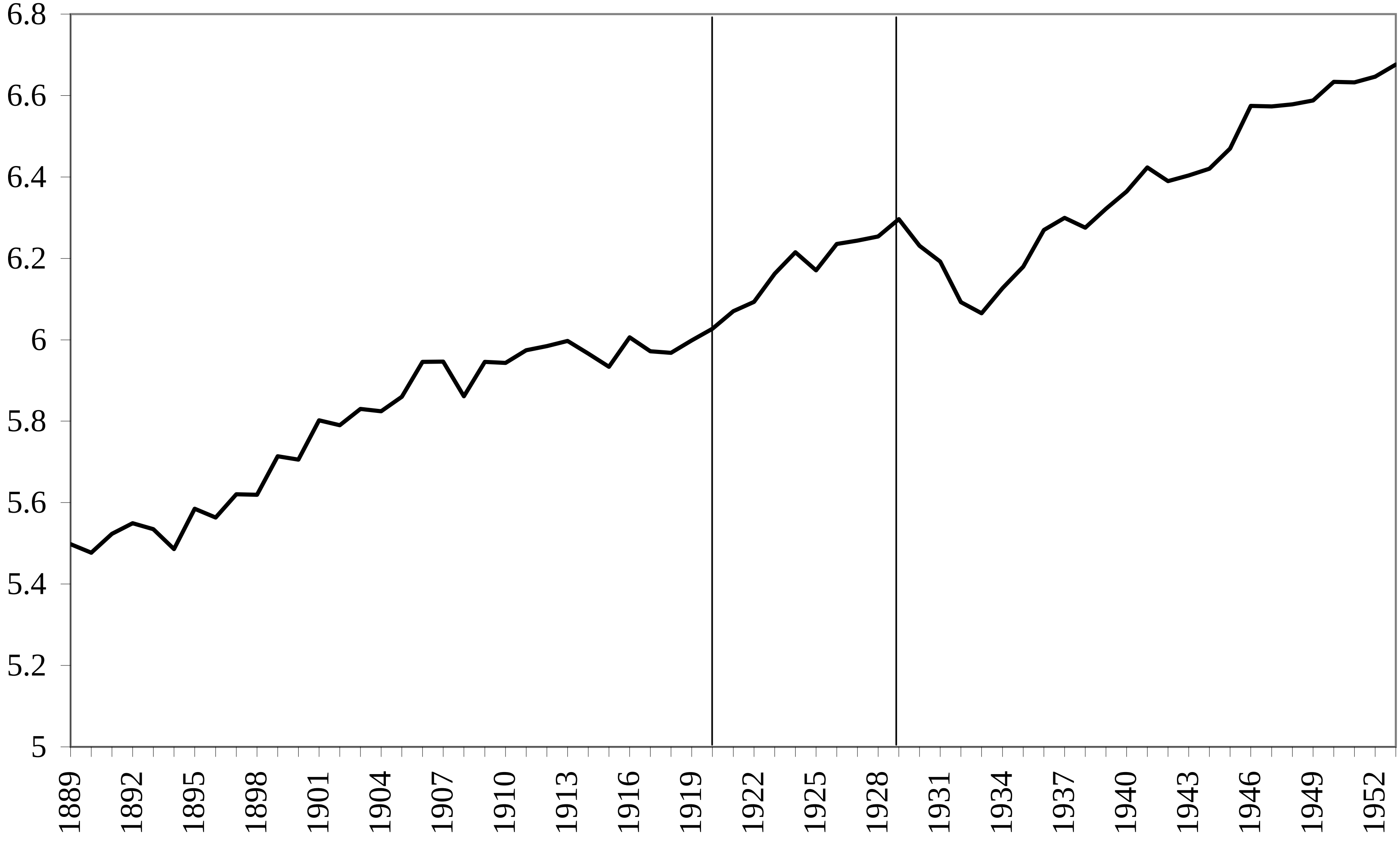

Figure 3: Technology Shocks

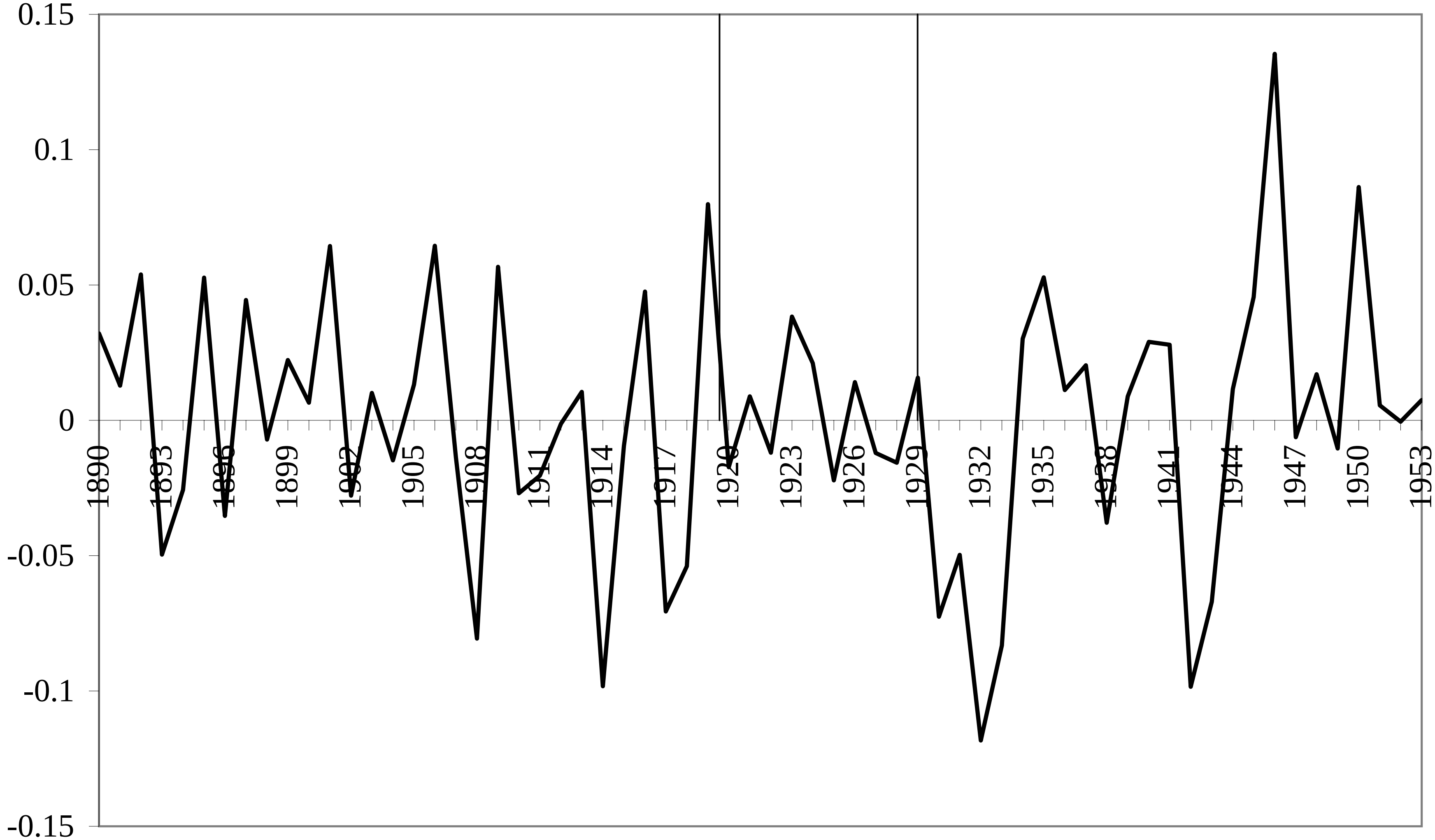

Figure 4: Sunspot Shocks

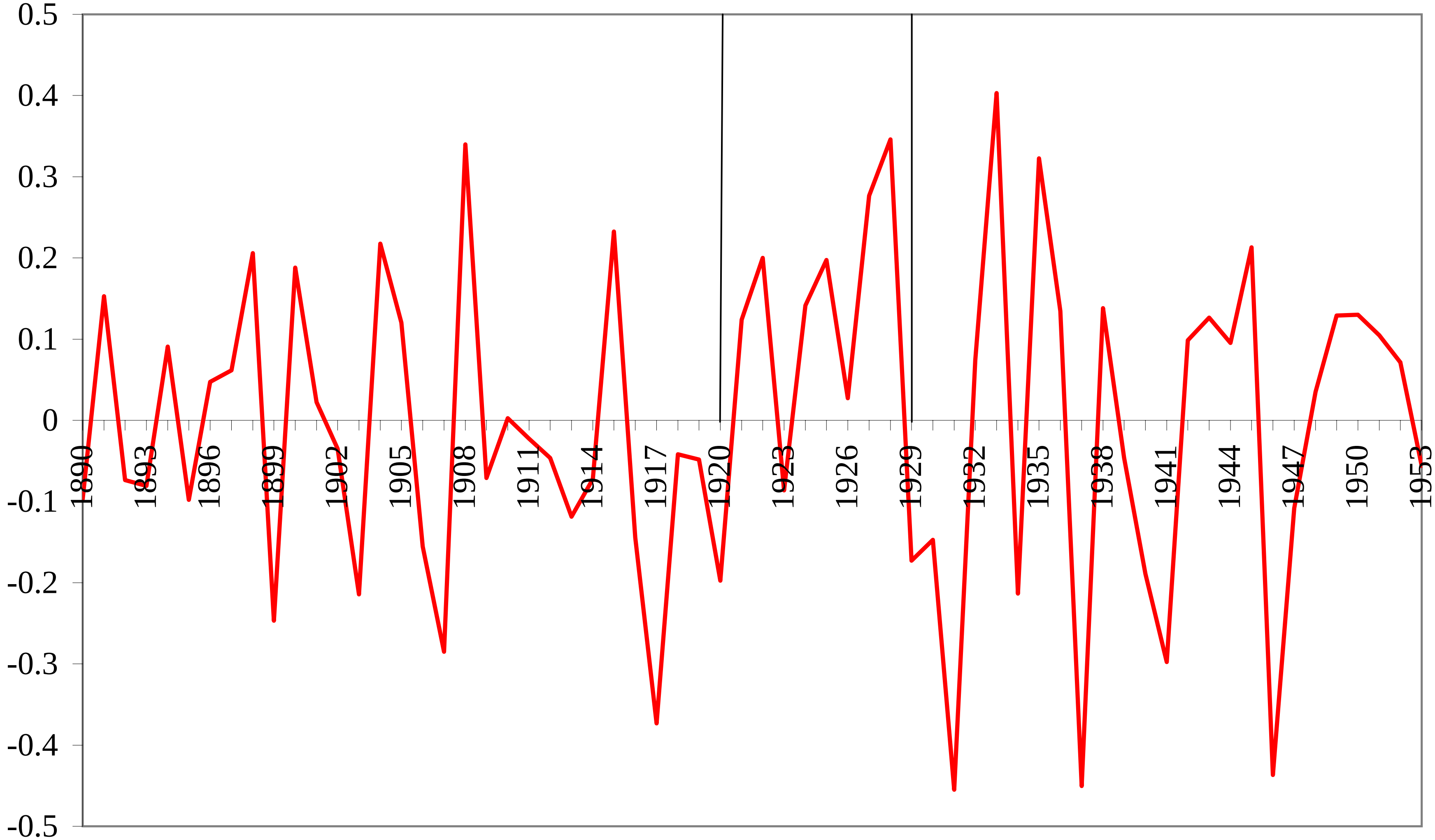

Figure 5: Log-linear detrended Output (Sunspots)

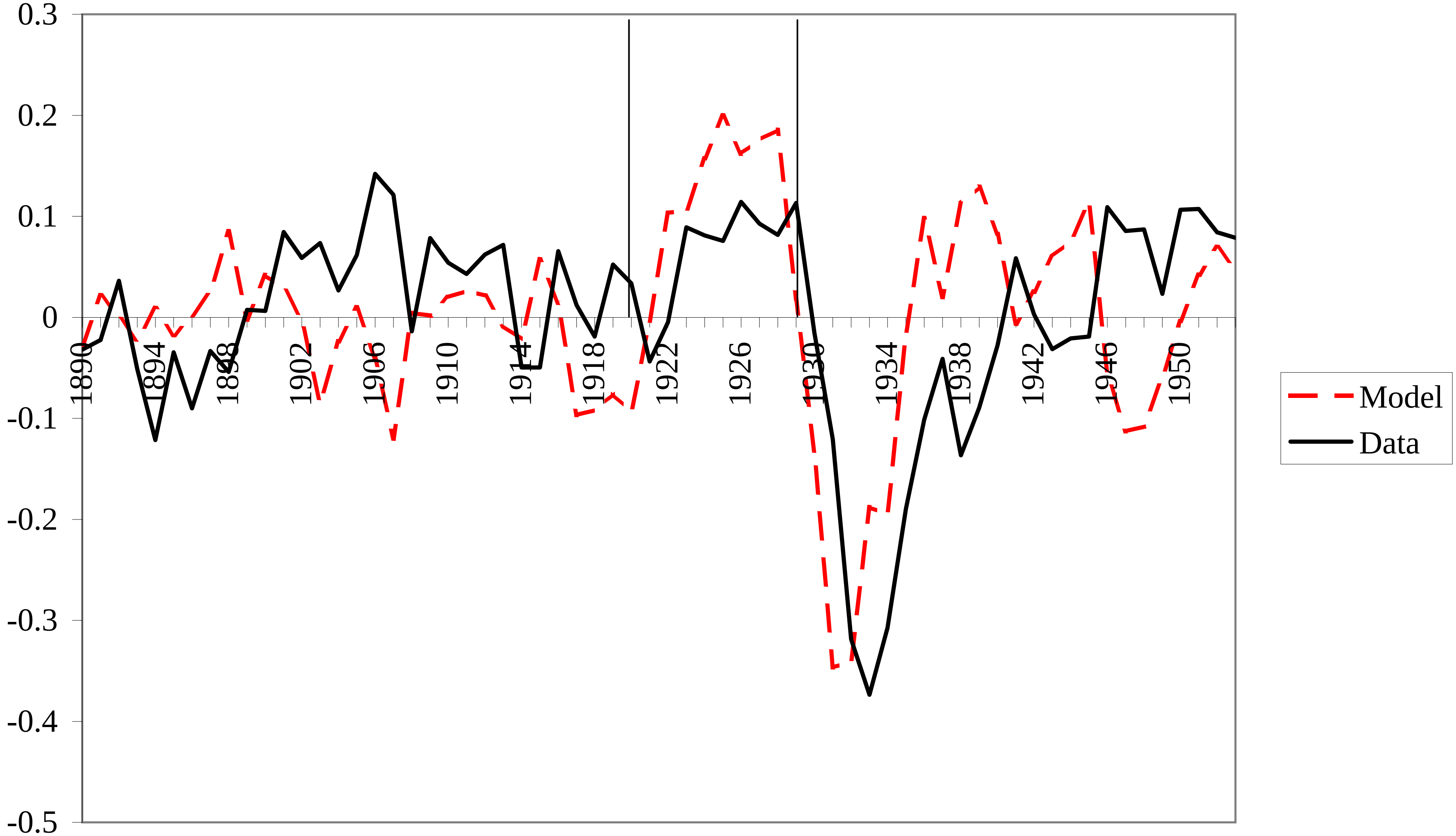

Figure 6: HP-Filtered Output (Sunspots)

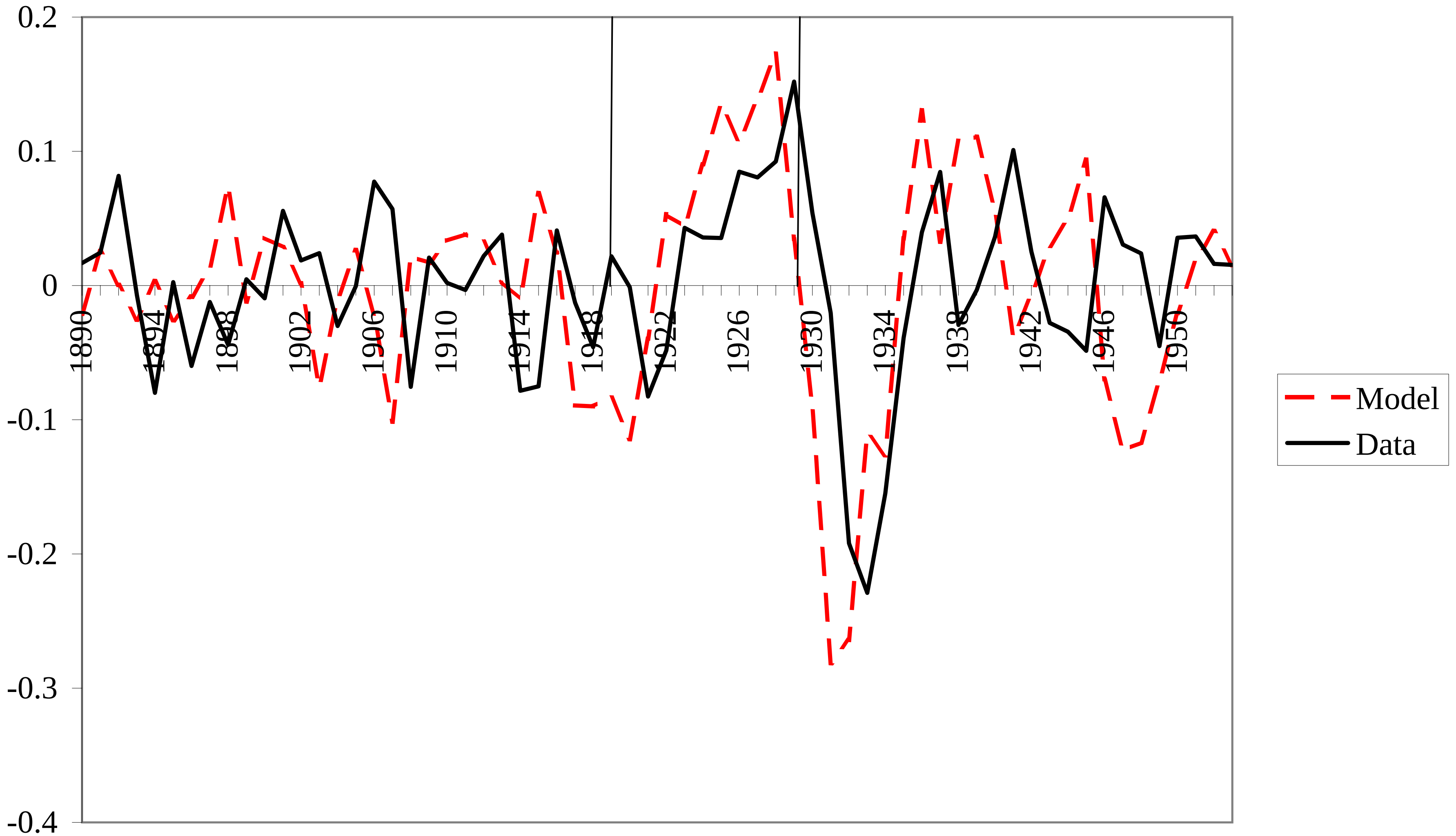

Figure 7: Log-linear detrended Consumption (Sunspots)

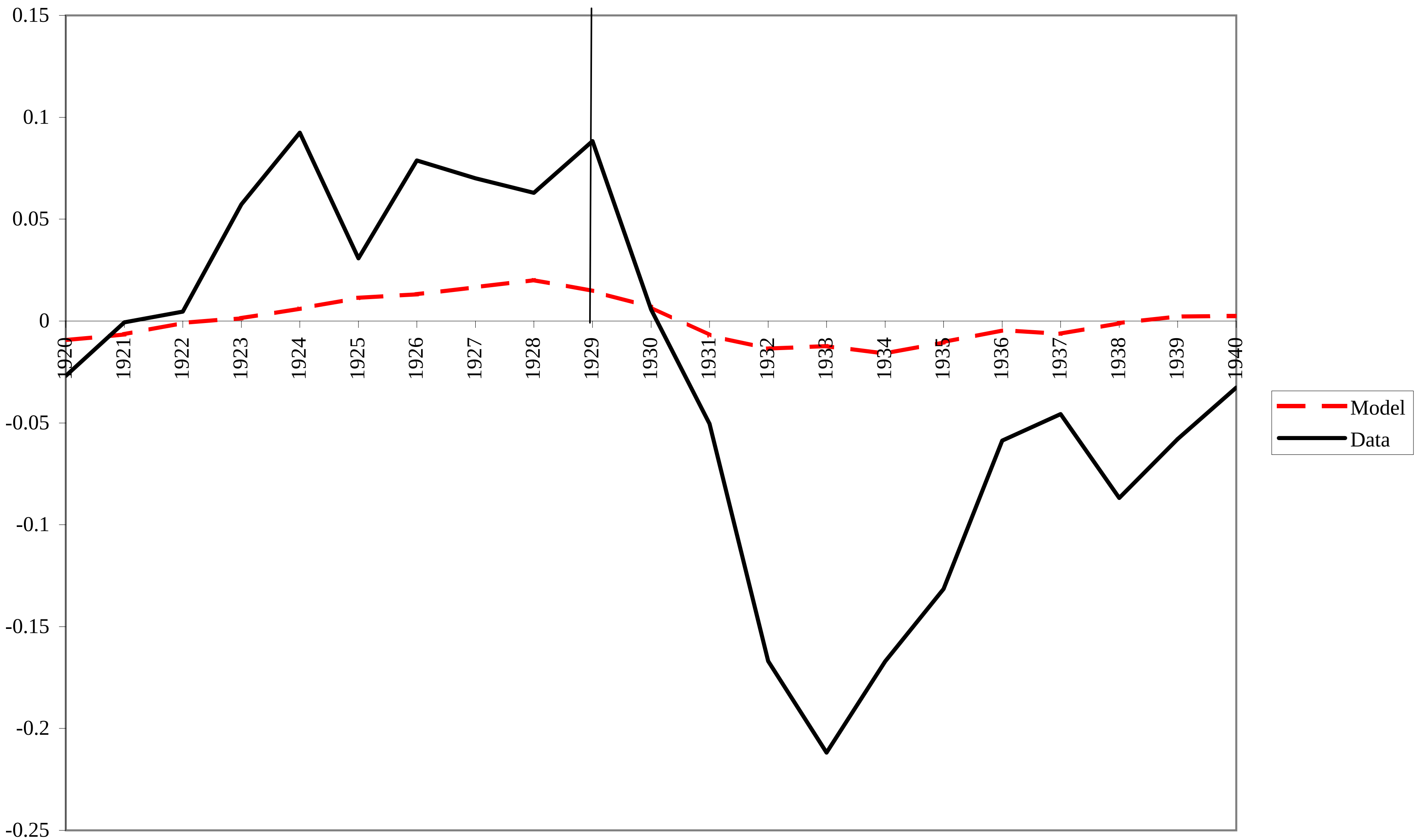

Figure 8: Log-linear Detrended US output (TFP shocks)

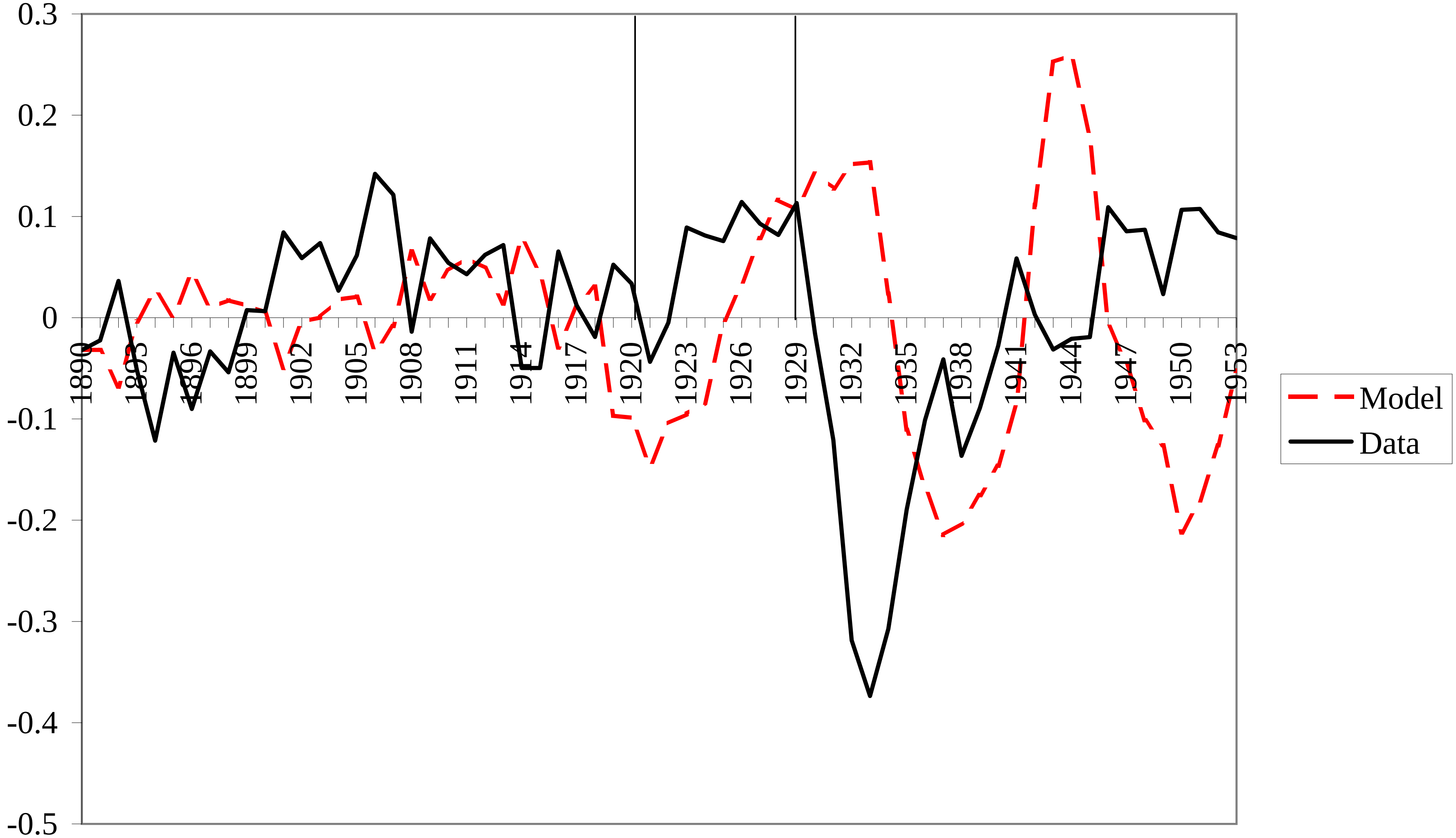

Figure 9: Log-linear Detrended Output (both shocks)