Federal Reserve Bank of Minneapolis
Research Department Staff Report 356

February 2005

Deflation and the International Great Depression: A Productivity Puzzle[*]

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ABSTRACT

This paper presents a dynamic, stochastic general equilibrium study of the causes of the international Great Depression. We use a fully articulated model to assess the relative contributions of deflation/monetary shocks, which are the most commonly cited shocks for the Depression, and productivity shocks. We find that productivity is the dominant shock, accounting for about 2/3 of the Depression, with the monetary shock accounting for about 1/3. The main reason deflation doesn't account for more of the Depression is because there is no systematic relationship between deflation and output during this period. Our finding that a persistent productivity shock is the key factor stands in contrast to the conventional view that a continuing sequence of unexpected deflation shocks was the major cause of the Depression. We also explore what factors might be causing the productivity shocks. We find some evidence that they are largely related to industrial activity, rather than agricultural activity, and that they are correlated with real exchange rates and non-deflationary shocks to the financial sector.

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[*] We acknowledge the support of the National Science Foundation (Cole SES 0137421 and Ohanian SES 0099250). We would like to thank Ben Bernanke, V.V. Chari, Larry Christiano, Pat Kehoe, Narayana Kocherlakota, Ellen McGrattan, Ed Prescott and Richard Rogerson for comments. We thank Yi-Li Chien for research assistance.

1. Introduction

Since Kydland and Prescott's (1982) study of postwar U.S. business cycles, it has become common practice to measure the relative contributions of different shocks to business cycle fluctuations using dynamic, stochastic general equilibrium models. This paper conducts this type of shock decomposition analysis for the international Great Depression, the 1929–33 period when many countries had macroeconomic declines. The international aspect of the Great Depression has attracted substantial interest because it brings cross-country evidence to bear on this singular event.[1] Despite the interest in the cross-country aspect of the Great Depression, we are unaware of any comprehensive cross-country studies using the DSGE methodology.[2] We therefore study macroeconomic activity in 17 countries between 1929 and 1933 using a fully articulated business cycle model. The question we address is: "What shock(s) caused the international Great Depression?" We first assess the type of shocks that are reasonable to include in a model economy for understanding the international Depression, and we then assess which shock is the most quantitatively important shock.

Regarding the type of shocks to include in a model economy, the international Great Depression literature stresses contractionary money/deflation shocks operating through imperfectly flexible nominal wages. We therefore include deflationary shocks operating through this wage channel in our model. We also include productivity shocks in the model because there are large and systematic changes in productivity across countries and because the cross-country relationships between output, deflation, and real wages are not easily reconciled by a sticky wage model driven by only monetary shocks, but can potentially be reconciled with productivity shocks.

We use the model to measure the relative fractions of output change accounted for by these two shocks. We find that the productivity shock is the dominant shock, accounting for about 2/3 of the output change in these countries between 1929 and 1933, with monetary

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[1] For example, Bernanke (1995) argues, "To my mind, the most significant recent development has been change in the focus of depression research to a more comparative approach that examines the experiences of many countries simultaneously."

[2] There are recent papers that have examined the Depression within a single country (primarily the United States) using the DSGE framework, including Beaudry and Portier (2002), Bordo, Erceg, and Evans (2000), Cole and Ohanian (1999, 2002, 2004), Crucini and Kahn (1996), Fisher and Hornstein (2002), Perri and Quadrini (2002). Amaral and MacGee (2002) focus on the Canadian Great Depression with some comparisons to the U.S. Most of these studies do not attempt a formal shock decomposition analysis.

shocks accounting for about 1/3. We also find that the quantitative importance of productivity is robust to modifications to the model economy. The dominant contribution of the productivity shock contrasts with the conventional wisdom that the international Depression was largely a monetary phenomenon.

Given the surprising nature of these findings, we examine why the money/deflation shock does not account for more of the Depression. The main reason is that the empirical correlation between deflation and output during the Depression is very different from that generated in the economic model by money shocks. Specifically, money shocks generate a correlation between deflation and output of nearly one in the model, while in the data this correlation is either negative or close to zero for most of the Depression.

We also conduct a deeper analysis of the productivity shocks to learn more about them and assess what factors may be driving these shocks. The most striking finding is that there is a large positive correlation between the productivity shocks and lagged changes in real stock prices that is significantly larger than the correlation between these variables in postwar business cycles. We use a version of Aiyagari's (1994) model to show that the stock market data provide independent evidence that a highly persistent productivity shock was the key factor driving the Depression. We also find that the productivity shocks are related to industrial activity, rather than agricultural activity, and that they may be related to financial shocks and real exchange rates, suggesting clues for further investigations.

The paper is organized as follows. Section 2 summarizes the cross-country data and discusses the shocks we include in the analysis. Section 3 presents the model. Section 4 discusses the accounting procedure we use to evaluate the contribution of money and productivity shocks, the parameterization of the model, and the accounting results, and explains the findings. Section 5 discusses alternative explanations of the productivity shocks, including capacity utilization, labor hoarding, and other factors. We find that these alternative explanations are not plausible. Section 6 discusses characteristics of the shocks. Section 7 compares the model to the data. Section 8 presents and interprets the correlation between lagged stock prices and productivity. Section 9 discusses the correlation between productivity shocks and the industrial share of the economy, financial shocks, and real exchange rates. Section 10 concludes. The Appendix lists data sources, describes technical details about the model, and presents additional tables.

2. The Shocks and Summary of the Data

The international Great Depression literature focuses on contractionary money/deflation brought about by the gold standard as the key shock driving the Depression.[3] Temin (1989) argues, "This massive international deflationary movement — a 20 percent fall in 2 years — is a key part of the story of the Great Depression" (1993). Bernanke (2004) argues, "The collapse of the money supply...that in many ways had a bias toward deflation built into it, seems clearly to have been the major single cause of the Depression."

Imperfectly flexible wages are cited by the literature as a key channel through which deflation caused the Depression. Bernanke (1995), Bernanke and Carey (1996), and Eichengreen and Sachs (1985), among others, tell a textbook "deflation-sticky wage" story in which unanticipated deflation raises real wages through incomplete nominal wage adjustment and which reduces employment as firms move up their labor demand schedules. Table 1 summarizes output, deflation, and real wage changes in our panel of countries and provides some evidence that the deflation/high real wage channel contributed to the Depression.[4] The first panel of the table shows that, on average, output fell, prices fell, and real wages rose in these countries. We therefore include monetary shocks operating through the sticky wage channel in our model.

Our cross-country data, however, suggest that deflation is not the only shock driving the international Great Depression. Figures 1A–D show cross-country scatter plots of log output deviations from 1929 and the annual percentage change in the price level for each year through 1933. If deflation was the only important shock, then we *should* see a strong positive cross-country relationship between price changes and output changes: the countries with the biggest deflations should have had the biggest depressions, and likewise, the countries with

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[3] Eichengreen (1992) discusses the importance of the gold standard in generating and propagating the worldwide deflation.

[4] The countries are Australia, Austria, Canada, Czechoslovakia, Denmark, Finland, France, Germany, Hungary, Italy, Japan, the Netherlands, Norway, Sweden, Switzerland, the U.K., and the U.S. Output is real GNP, the price level is the GNP deflator, and the wage rate is for the industrial/manufacturing sector. We selected these countries because of the availability of GDP, the deflator, and a wage index. (The price index for Czechoslovakia is the CPI rather than the deflator.) The data have not been detrended, because there may be differences in trends across countries. However, this should not matter too much over the 4-year data window we consider.

the smallest deflations should have had the smallest depressions. The empirical relationship between these variables, however, is very different. The second panel of Table 1 shows that the correlation between price changes and output changes are either negative or small in three of the four depression years. The lack of a strong and systematic positive relationship between output and deflation suggests that it is useful to consider an additional shock.

Table 2 shows the cumulative log change in output and in the deflator through 1932 for each of these countries. This table also suggests another shock is operative. The table shows that many countries had similar deflation rates, but had very different output changes. For example, the United States and Italy both had 24 percent deflations between 1929 and 1932, but real GNP fell 33 percent in the United States, compared to only a 7 percent decline in Italy.

We now show that this additional shock appears to be quantitatively important. We demonstrate this by showing that the best-fitting single shock (log-linearized) model driven only by unanticipated contemporaneous deflation accounts for a small fraction of the international Great Depression. To see this, first note that output change in any log-linearized, DSGE model without endogenous state variables like capital, and in which unexpected contemporaneous deflation is the single operative shock, can be written as

$$y_t = \alpha \pi_t,$$

where y_t is the log-deviation of output from its steady-state value, π_t is deflation, and α is the parameter governing the impact of this deflation on output. This approximation is typically quite accurate over short intervals since capital changes slowly and therefore contributes comparatively little to business cycle fluctuations in output.

The value of α depends on the details of the particular economic model. In this exercise, we will find the value for α that maximizes the fit by using OLS. We therefore estimate the following equation for our panel of 17 countries between 1930 and 1933:

$$(1) \quad y_{it} = \alpha \pi_{it} + \varepsilon_{it},$$

where the dependent variable is the log-deviation of output between year t and 1929, and π_{it} is the percentage change in the price level in country i between year $t-1$ and t.[5] This regression explains 23 percent of the sum of squared output deviations. The fact that most of the depression remains unexplained in the best-fitting log-linearized deflation model suggests that the other shock contributing to the Depression is quantitatively important.[6]

The second shock we include in the model is a productivity shock. There are three reasons for this choice. The first is there are large and systematic changes in productivity across countries. Figure 2 shows the output change and productivity change for the seven countries for which we have aggregate productivity data. We have total factor productivity (TFP) for five countries (Canada, France, Germany, the United Kingdom, and the United States) and labor productivity for two countries (Australia and Japan). The figure shows that the countries with large depressions (Canada, France, Germany, and the United States) generally had large productivity declines, and the countries with mild depressions or expansions (Australia, Japan, and the United Kingdom) did not have these large productivity declines. Appendix table A3 shows this data.

There is also a strong positive relationship between productivity and output in the 11 countries for which we have industrial labor productivity (rather than aggregate labor productivity) during the Great Depression. The correlation between the log-deviation in industrial productivity and GDP in 1932 relative to 1929 is 0.64. This is slightly higher than the annual postwar U.S. correlation between the HP filtered log of real GDP and the HP

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[5] The explanatory power in this particular equation can be viewed as an upper bound because we place no economic restrictions on the size of the parameter α and because we abstract from any need to use instruments for deflation.

[6] An alternative interpretation is that the Depression was driven just by deflation, but through a more complicated model that is poorly approximated by a log-linearized model driven solely by contemporaneous deflation. While a comprehensive assessment of this possibility is beyond the scope of this paper, we later present statistical results for more complicated deflation-based models and show that these other models, including ones with lagged values of deflations, and with country-specific responses to deflation, also account for a small fraction of the Depression.

filtered log of industrial labor productivity, which is 0.55.[7]

A second reason we add productivity shocks is the cross-country relationship between real wages and output. Figures 3A–D show annual scatter plots between log output deviations from 1929 and real wage changes, and the second panel of Table 1 shows the correlation between real wages and output. The key feature of these data is that the correlation between real wages and output is either slightly positive or around zero. This stands in sharp contrast to the -1 correlation generated by deflation in a sticky wage model. The lack of a systematic, negative correlation means that the second shock needs to be a *labor demand shifter*, and a productivity shock satisfies this requirement.

The third reason we choose productivity is because the regression residual from the output-deflation regression estimated above is similar to labor productivity fluctuations in these countries (for the countries for which we have these data). The correlation between these two series is 0.40. The fact that productivity is similar to this residual component of output suggests that productivity is a complementary factor to deflation and also suggests that these two shocks — money and productivity — might account for much of the international Depression. We therefore abstract from other shocks.[8]

We stress that our study analyzes the contributions of the shocks that caused the Depression (1929–33). We do not analyze the recovery from the Depression. A recovery analysis is important and interesting in its own right, but is beyond the scope of this paper, because a recovery analysis would need to take into account the different types of government programs countries adopted in response to the Depression. For example, Cole and Ohanian (2004) present an analysis of these programs for the U.S. recovery and argue that these programs significantly affected the U.S. recovery.

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[7] We computed this value for both HP smoothing parameters 6.25 and 400.

[8] We also omit other shocks from the model because it is unclear what other shocks are reasonable ones for the majority of countries, and because introducing other shocks in some cases requires substantial and complicated changes in the model. For example, some economists suggest that tariffs may have been important for at least some countries, but this would require the development of an open-economy framework for these 17 countries. We therefore restrict the analysis to two shocks, and we later assess whether the productivity shocks might be serving as proxies for factors that we have omitted.

3. The Model

Quantifying the role of monetary/deflation shocks requires a model with a monetary nonneutrality. We follow the conventional view that the nonneutrality during the Great Depression operated through imperfectly flexible nominal wages. We introduce nominal wage inflexibility using an information imperfection that is in the spirit of the Lucas (1972) misperceptions model. Specifically, we assume that households make their labor supply decisions without full information; they know the nominal wage when choosing their labor supply, but they don't know the current innovations to the money supply shocks and productivity shocks. Qualitatively, this imperfect information model works exactly like a standard predetermined wage model, but differs quantitatively.[9] Before describing our misperceptions model, we explain the two reasons we use this model rather than a standard predetermined wage model.

The first reason is that the nonneutrality of money is much too large in the standard predetermined wage model, because it predicts way too large a depression for almost every country in our sample in response to the observed deflation rate, and it generates grossly counterfactual labor productivity. For example, the sticky wage model misses U.S. labor productivity by 26 percentage points: actual labor productivity is 18 points below its 1929 level, while the sticky wage model generates an 8 percent increase in labor productivity. We therefore need a model which has a smaller nonneutrality. Our misperceptions model has a smaller nonneutrality and in log-linearized form is otherwise identical to the standard predetermined wage model. The Appendix establishes this result.[10] Note that our model has the exact deflation–real wage mechanism stressed in the Depression literature.

The second reason is that it is easy to check whether the decomposition results depend on different values of the nonneutrality. This is because the nonneutrality in this misperceptions model takes on a range of values that is governed by the relative variances of the productivity and money shocks. This means that the shock decomposition results can be

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[9] The sticky wage model we have in mind is one in which workers are imperfect substitutes in production and set their nominal wages each period before knowing the monetary and productivity shocks. (See Cole and Ohanian (2001) or Chari, Kehoe, and McGrattan (2002).)

[10] Alternatively, we could have reduced the size of the nonneutrality either by shortening the length of the period in which wages are fixed or by constructing a multisector model in which only some wages are fixed. Both of these approaches, however, are complicated. The first approach is complicated because the data are available on only an annual frequency. The second approach is complicated because it requires constructing an explicit multisector model. The misperceptions model is simpler to use than either of these alternatives.

easily assessed for different sizes of the monetary nonneutrality. We now turn to the details of the misperceptions model.

Preferences: There is a large number of identical households who have preferences over sequences of a cash good, a credit good, and leisure. We normalize the size of the population to one.

Preferences for the household are given by

$$(2) \quad E\sum_{t=0}^{\infty}\beta^t\left\{\log([\alpha {c_{1t}}^{\sigma}+(1-\alpha){c_{2t}}^{\sigma}]^{1/\sigma})+\phi\log(1-n_t)\right\},$$

where c_1 is the cash good, c_2 is the credit good, and $1-n$ is nonmarket time. The household maximizes (2) subject to the following constraints:

$$\begin{aligned} & m_t+w_tn_t+r_tk_t+(T_t-1)M_t \\ & \geq m_{t+1}+p_t\left[c_{1t}+c_{2t}+k_{t+1}-(1-\delta)k_t\right], \end{aligned}$$

$$p_tc_{1t}\leq m_t+(T_t-1)M_t.$$

The household's nominal wealth is the sum of its beginning-of-period cash holdings m_t, its labor income w_tn_t, its capital income r_tk_t, and a lump-sum monetary transfer from the government $(T_t-1)M_t$, where T_t is the gross growth rate of the money stock. The household's wealth is used to finance the sum of the cash the household carries into the following period m_{t+1} plus its purchases of cash goods, credit goods, and investment $p_t[c_{1t}+c_{2t}+k_{t+1}-(1-\delta)k_t]$.

The cash-in-advance constraint is standard and requires that the stock of cash carried over by the household from the previous period, plus the lump-sum monetary transfer it receives from the government, is sufficient to pay for cash goods p_tc_{1t}.

Technology: Output is produced from a constant returns to scale Cobb-Douglas technology:

$$Y_t=Z_tK_t^{\theta}N_t^{1-\theta},$$

where Z is a technology shock that follows a first-order lognormal autoregressive process:

$$Z_t = e^{\hat{z}_t},\ \hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_{zt}, \varepsilon_{zt} \sim N(0, \sigma_z^2).$$

The resource constraint is

$$C_{1t} + C_{2t} + X_t \leq Y_t.$$

The transition rule for capital is

$$K_{t+1} = (1-\delta)K_t + X_t.$$

Monetary Policy: Monetary policy is given by changes in the gross growth rate of money, which follows a first-order lognormal autoregressive process:

$$T_t = \bar{\tau} e^{\hat{\tau}_t},\ \text{where } \hat{\tau}_t = \rho_\tau \hat{\tau}_{t-1} + \varepsilon_{\tau t}, \varepsilon_{\tau t} \sim N(0, \sigma_\tau^2).$$

The change in the money stock at the beginning of the period is thus equal to $(T_t - 1)M_t$, and the total money stock at the beginning of the period is given by

$$M_{t+1} = T_t M_t.$$

Imperfect Information and the Timing of Transactions: We now specify the timing of information and the timing of activities within a period. To do this, we first need to define the state of the economy, which we denote by $S_t = (K_t, \hat{z}_{t-1}, \hat{\tau}_{t-1}, \varepsilon_t^z, \varepsilon_t^\tau)$. Note that we include the lagged values of the shocks and their current innovations separately in the state vector, because the model requires that households make their labor market choices before they observe $(\varepsilon_t^z, \varepsilon_t^\tau)$.

At the start of a period, the household knows its own state (k_t, m_t), knows a subset of the state vector $\bar{S}_t = (K_t, \hat{\tau}_{t-1}, \hat{z}_{t-1})$, and knows the nominal wage. Note that households do not know the realizations of the money supply or technology innovations. We assume that the representative firm knows the full state vector.[11] At this stage, the labor market opens, and the household and firm make their labor market choices, given the nominal wage. Note that households make their labor market choice without knowing the full state vector. After the labor market closes, the full aggregate state $S_t = (K_t, \hat{z}_{t-1}, \hat{\tau}_{t-1}, \varepsilon_t^z, \varepsilon_t^\tau)$ is revealed, and households receive their monetary transfer from the government. The household then supplies the labor that it previously committed to supply in the labor market. Note that workers cannot re-contract the quantity of work after they learn the values of the technology and productivity innovations. (Otherwise, money would be neutral.) At this stage, workers also rent capital to the firm and acquire cash consumption goods, credit consumption goods, and investment goods. At the end of the period, firms and labor settle their remaining transactions, with firms paying households for their labor and capital services, and households paying firms for credit consumption goods and investment goods.

A Recursive Formulation: To construct a recursive formulation, we denote the law of motion for aggregate capital by $H(S_t)$, and we make the economy stationary by dividing all period t nominal variables by $M_{t-1}T_{t-1}$, which implies that the normalized beginning-of-period aggregate money stock is $(m_t = 1)$. This stationary-inducing transformation also implies the following rule that governs the transition between the quantity of money chosen by the household in period t $(\tilde{m}_{t+1})$ and the quantity of money that the household has at the start of period $t+1$ (m_{t+1}) :

$$m_{t+1} = \tilde{m}_{t+1}/T_t.$$

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[11] These assumptions about the household's information set and the firm's information set are natural to make in this environment, given that we are using this simple environment to stand in for a richer environment in a multisector model producing heterogeneous consumer goods. In such an environment, firms care about only four variables in the model: their product price, the state of their technology, and the rental prices of labor and capital. It seems plausible that the firm would know a lot about these variables just prior to production. The households in such an environment would care about many more variables than a firm would. In particular, the household would care about the entire distribution of prices in the economy. It seems plausible that households would have only imperfect information about the entire distribution at the start of the period. To match the larger informational frictions faced by households within our simple model, we assume that firms know the full state vector, which implies they know their technology and the prices, while households do not know the current shocks.

This transition rule implies that the money stock is constant over time, and we denote this constant stock as M. We use this transition equation in the household's budget constraint below, substituting $T_t m_{t+1}$ for $\tilde{m}_{t+1}$.

The representative household has a two-stage maximization problem in this model. The Bellman equation for the household is given by

$$V(m_t, k_t, \bar{S}_t, w_t) =$$
$$\max_{n_t} E_{(\bar{S}_t, w_t)} \left\{ \begin{array}{c} \max_{c_{1t}, c_{2t}, m_{t+1}, k_{t+1}} \ \log([\alpha c_{1t}{}^{\sigma} + (1-\alpha) c_{2t}{}^{\sigma}]^{1/\sigma}) + \phi \log(1 - n_t) \\ +\beta E_{S_t} V(m_{t+1}, k_{t+1}, \bar{S}_{t+1}, w_{t+1}) \end{array} \right\}$$

subject to

$$m_t + w_t n_t + r_t k_t + (T_t - 1)M \geq m_{t+1} T_t + p_t \left[k_{t+1} - (1-\delta)k_t + c_{1t} + c_{2t}\right]$$

$$m_t + (T_t - 1)M \geq p_t c_{1t}$$

and subject to the stochastic processes for the shocks. In the first stage maximization, the household chooses its labor supply, given $\bar{S}_t$ and given the nominal wage. Thus, it optimally forecasts the technology and monetary shocks from the current state and the nominal wage. This can be seen in the household's first-order condition for choosing labor:

$$-\phi/(1 - n_t) + w_t E\{\lambda_t | w_t, \bar{S}_t\} = 0.$$

The household equates the marginal utility of leisure to the *expected* marginal utility of nominal wealth (λ_t), scaled by the nominal wage. The household solves this expectational equation using standard signal extraction formulae. We present the details of this signal extraction in the Appendix.

After the household chooses its labor supply, the full state is revealed and the household chooses cash goods consumption, credit goods consumption, money holdings for next period, and investment during the second stage.

Producer's Problem: The firm's maximization problem is standard, because it knows the full state vector:

$$\max_{K_t,N_t} p_t Z_t(K_t)^{\theta}(N_t)^{1-\theta} - w_t N_t - r_t K_t.$$

Market-Clearing and Aggregate Consistency Conditions: The market-clearing conditions are

$$M = m_{t+1},$$

$$Y_t = C_{1t} + C_{2t} + K_{t+1} - (1-\delta)K_t,$$

$$N_t = n_t,$$

$$K_t = k_t.$$

The aggregate consistency condition is

$$k_{t+1} = H(S_t),$$

where $H(S_t)$ is the law of motion for the aggregate capital stock. In summary, a central feature of this model is that an unexpected monetary contraction raises the real wage and drives down employment as stressed in the international Depression literature.

A. The Role of Imperfect Information

This section illustrates how the information imperfection generates the monetary nonneutrality by analyzing the impact of an i.i.d. money shock in the log-linearized model. There are two key equations for understanding the nonneutrality of money: the household's labor-leisure first-order condition and the firm's demand-for-labor condition. We first consider the household's labor-leisure choice. Log-linearizing, we obtain

$$\text{Misperceptions Model: } \hat{w}_t - \frac{\hat{n}_t N}{1-N} = -E\{\hat{\lambda}_t|\hat{w}_t, \bar{s}_t\},$$

where capital letters are steady-state values of variables and the other variables are log-deviations from the steady state. With imperfect information, the household makes its labor supply decision by forecasting the marginal value of nominal wealth ($\hat{\lambda}_t$), conditioning on the nominal wage ($\hat{w}_t$) and the restricted state vector ($\bar{s}_t = (\hat{k}_t, \hat{z}_{t-1}, \hat{\tau}_{t-1})$). (Note that in the model with full information, the household knows the marginal value of nominal wealth.)

We now show how the household forecasts the marginal value of wealth, and how money shocks affect employment and output. First, note that the household knows the linear law of motion for the economy. The equation for $\hat{\lambda}_t$ is given by

$$\hat{\lambda}_t = D_{\lambda k}\hat{k}_t + D_{\lambda z}\hat{z}_{t-1} + D_{\lambda \tau}\hat{\tau}_{t-1} + D_{\lambda \varepsilon^z}\varepsilon_t^z + D_{\lambda \varepsilon^\tau}\varepsilon_t^\tau,$$

where $D_{\lambda j}$ is the linearized coefficient on state variable j. Similarly, the wage equation is given by

$$\hat{w}_t = D_{wk}\hat{k}_t + D_{wz}\hat{z}_{t-1} + D_{w\tau}\hat{\tau}_{t-1} + D_{w\varepsilon^z}\varepsilon_t^z + D_{w\varepsilon^\tau}\varepsilon_t^\tau.$$

Given $\bar{s}_t$ and $\hat{w}_t$, the workers forecast

$$\hat{\lambda}_t - E\{\hat{\lambda}_t|\bar{s}_t\} = D_{\lambda \varepsilon^z}\varepsilon_t^z + D_{\lambda \varepsilon^\tau}\varepsilon_t^\tau$$

from observing

$$\hat{w}_t - E\{\hat{w}_t|\bar{s}_t\} = D_{w\varepsilon^z}\varepsilon_t^z + D_{w\varepsilon^\tau}\varepsilon_t^\tau.$$

The solution to this standard signal extraction problem is

$$E\{\hat{\lambda}_t|\hat{w}_t, \bar{s}_t\} - E\{\hat{\lambda}_t|\bar{s}_t\} = \eta\left[\hat{w}_t - E\{\hat{w}_t|\bar{s}_t\}\right],$$

where η is the signal extraction parameter to be defined. Rewriting this equation yields

$$E\{D_{\lambda \varepsilon^z}\varepsilon_t^z + D_{\lambda \varepsilon^\tau}\varepsilon_t^\tau | D_{w\varepsilon^z}\varepsilon_t^z + D_{w\varepsilon^\tau}\varepsilon_t^\tau\} = \eta\left(D_{w\varepsilon^z}\varepsilon_t^z + D_{w\varepsilon^\tau}\varepsilon_t^\tau\right).$$

The optimal forecast of $\hat{\lambda}_t$ is given by

$$E\{\hat{\lambda}_t|\hat{w}_t, \bar{s}_t\} = [D_{\lambda k}, D_{\lambda z}, D_{\lambda \tau}, \eta D_{w\varepsilon_z}, \eta D_{w\varepsilon_\tau}] * s_t,$$

where the parameter η is given by

$$(3) \qquad \eta = \frac{D_{\lambda\varepsilon^z} D_{w\varepsilon^z}\sigma^2_{\varepsilon_z} + D_{\lambda\varepsilon^\tau} D_{w\varepsilon^\tau}\sigma^2_{\varepsilon\tau}}{(D_{w\varepsilon^z})^2\sigma^2_{\varepsilon z} + (D_{w\varepsilon^\tau})^2\sigma^2_{\varepsilon\tau}}.$$

The parameter η depends on variances of the money and productivity shock innovations, and on linearization coefficients. This parameter lies between 0 and -1. It is 0 when the variance of money shocks is 0. This is because with log utility, a productivity shock has no effect on the marginal value of nominal wealth, and thus $D_{\lambda\varepsilon^z} = 0$. It is -1 when the variance of productivity shocks is 0. This is because money shocks raise the nominal wage one-for-one, ceteris parabus, and reduce the marginal value of nominal wealth one-for-one ($D_{w\varepsilon^\tau} = 1$, and $D_{\lambda\varepsilon^z} = -1$).

We now use the firm's linearized first-order condition for labor to show how a money shock affects labor. This condition is given by

$$(4) \qquad \hat{n}_t = -\frac{1}{\theta}(\hat{w}_t - \hat{p}_t) + \frac{1}{\theta}\hat{z}_t + \hat{k}_t,$$

where θ is the exponent on capital in the production function.

Now, consider a one-time negative money shock that ultimately lowers the price level by 10 percent. This contractionary monetary shock implies that the nominal wage must fall to clear the labor market. If $\eta = -1$ (the case when the variance of the productivity shock is 0) then money is neutral: the nominal wage falls 10 percent, and this fall leads workers to revise their forecast of $\hat{\lambda}_t$ upward by 10 percent. Consequently, there is no change in labor supply, no change in the real wage, and no change in equilibrium employment or any other real variable.

Next, we consider the other polar case, which is $\eta = 0$. (The variance of money shocks is 0.) Just as before, the contractionary money shock must also drive down the nominal wage to clear the labor market. However, in this case the household infers that the lower nominal wage is entirely due to the real shock, rather than the monetary shock. Thus, it perceives that the real return to working has decreased. This misperception leads households to reduce their labor supply. Consequently, the equilibrium nominal wage falls, but less than the price level. The real wage rises, and employment and output fall.

The reason that this model has a smaller nonneutrality than the predetermined wage model is that the nominal wage in this model partially responds to shocks in order to clear the labor market. The extent of that response depends on the nonneutrality parameter η. In the standard predetermined wage model, the nominal wage is fixed, which means all the adjustment comes from the firms moving up their labor demand curves.

In summary, a contractionary money shock works in this model just as in the standard international Depression story: a negative money shock drives up the real wage through deflation and imperfect nominal wage adjustment, generating lower employment and output.

4. Accounting for the International Great Depression

We first describe our accounting procedure and then report the relative contributions of the two shocks to the Depression.

A. An Accounting Procedure

We measure the contribution of each shock as the percentage of the sum of squared output deviations accounted for by each shock individually:

$$(5) \quad 1 - \frac{\sum_{i=1}^{17} \sum_{t=1930}^{1933} (y_{it}^{p} - y_{it})^2}{\sum_{i=1}^{17} \sum_{t=1930}^{1933} {y_{it}}^2},$$

where y_{it} is the log-deviation of real output from its 1929 level in country i in period t and y_{it}^{p} is the model-predicted log-deviation of real output from its 1929 level for each shock individually.

This analysis faces two complications. The first is measuring the shocks. Unfortunately, TFP can be constructed for only 5 of the 17 countries, and money shocks are latent variables.[12] Given these limitations, we treat both shocks as latent variables, and we construct

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[12] It might be possible to statistically model the money process and back the shocks out, but there is no standard statistical model of the money process during this period. Moreover, this would be further complicated by the possibility of money demand shocks. See Field (1984) and Christiano, Motto, and Rostagno

country-specific productivity shocks and country-specific monetary shocks so that output and the price level in the model for each country and for each year matches the actual output and price data. We match the price level because of the view in the literature that deflation is an important contributing factor to the Depression. We match output to conduct the shock decomposition. The shocks are constructed as the variables that solve the two linear equations from the model that govern the log price deviation and the log output deviation. We will later compare the constructed productivity shocks in the model to actual productivity.

The second complication is that the constructed shocks have nonzero means and a nonzero covariance. This has implications for assessing the relative contribution of the two shocks, because with nonzero means and nonzero covariances, the sum of the two fractions obtained from (5) may differ from one. We deal with this complication by allocating the mean and covariance components of the shocks to construct maximum and minimum bounds on the contribution of each shock so that the sum of the bounds is one.

To do this, we first write each shock as the sum of three components: (1) a mean component (m), (2) an uncorrelated zero-mean component (u), and (3) a correlated zero-mean component (v). Since the mean terms and covariance terms differ each year, we need to specify year-specific mean and covariance components for this decomposition:

$$\begin{aligned}
\varepsilon_{zt} &= m_{zt} + u_{zt} + v_t, \\
\varepsilon_{\tau t} &= m_{\tau t} + u_{\tau t} + \gamma_t v_t.
\end{aligned}$$

Our bounds construction procedure extends the standard variance decomposition procedure that operates on zero-mean random variables to non-zero-mean random variables. Recall that the standard variance decomposition problem is to decompose the variance of a random variable that is the sum of two zero-mean correlated shocks. The standard resolution of this problem for zero-mean variables is to construct bounds for the contribution of each variable by attributing the covariance term to one shock and then to the other shock. Our procedure allocates the covariance term between the shocks in this same way. We also must allocate the mean components, because the means of the two shocks may be related. For example,

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(2004) for some evidence that these shocks were large.

the mean of the money shock may be a linear function of the mean of the productivity shock. Since we cannot separate the two means into a common component and an idiosyncratic component, we construct the bounds by attributing all of the mean components to one shock and then to the other shock.

The *minimum bound* for the productivity shock is therefore the fraction of squared output deviations explained in (5), calculating y_{it}^p just from the zero-mean orthogonal component of the productivity shock, u_{zt}. It is the minimum bound because we are attributing the contribution from the correlated zero-mean common component (v_t) and the mean components to the money shock. The *minimum bound* for the money shock is constructed in a similar fashion using $u_{\tau t}$. We calculate $u_{\tau t}$ as the residual from a regression of $\varepsilon_{\tau t}$ on a constant and ε_{zt}. Recall that because the mean and covariance terms differ each year, this regression is estimated for each year. Similarly, we calculate u_{zt} as the residual from the regression of ε_{zt} on a constant and $\varepsilon_{\tau t.}$ The *maximum bound* for the money shock is just one minus the lower bound for the productivity shock, and similarly the *maximum bound* for the productivity shock is one minus the lower bound for the money shock.

One interpretation for the lower bound of the contribution of the money shock is that the money supply process responds to the productivity shock, as would be the case if a central bank were targeting the gold value of its currency or targeting another endogenous variable. An interpretation of the lower bound on productivity is that there is an unmodeled impact of the money shock on productivity, such as changes in capacity utilization.

B. Parameter Values

Table 3 presents the parameter values. A number of these values are standard in the literature and also do not affect the decomposition results. We set the discount rate to 0.95, the exponent on labor in the production function to 2/3, and the depreciation rate to 7 percent per year, which yields a steady-state capital/output ratio of 2.7. We choose the preference parameters α and σ such that the steady state of the model matches two long-run money demand observations: an interest semi-elasticity of money demand of $-.08$ and an average velocity level of 3.2. We choose the leisure parameter ϕ so that households spend about 1/3 of their time working in the deterministic steady state.

We choose the autocorrelation coefficient for the technology shock to be 0.9. We choose the autocorrelation coefficient for money growth (ρ_τ) to be zero, which is consistent with the average serial correlation of money growth during the gold standard period. We conduct a sensitivity analysis for values of the money growth serial correlation parameter between -0.5 and 0.5 and find that our results were insensitive to values in this range.

The innovation variances for the money supply and the technology shock determine the size of the impact of an unanticipated money shock on output. We label this nonneutrality parameter η. We therefore choose a value for η rather than individually choose the innovation variances. Table 4 displays the impact of a contractionary money shock that reduces the price level by 10 percent for different values of η. The maximum nonneutrality decreases hours by about 15 percent from a 10 percent decrease in the price level. The medium nonneutrality ($\eta = -.5$) decreases hours by about 10 percent in response to a 10 percent deflation.[13]

We choose a benchmark value for η such that productivity changes in the model are similar to those in the data. This turns out to be the mid-range value, $\eta = -.5$. To understand the implications of η for labor productivity, note that for a money shock of a given size, a large nonneutrality drives down employment significantly by shifting the labor supply schedule. This increases labor productivity and the real wage. In contrast, in a neutral model, which is $\eta = -1$, a monetary shock will not shift the labor supply schedule, and employment and labor productivity will be driven entirely by a productivity shock. Thus, contractionary monetary shocks drive labor productivity higher, with the size of the impact depending on the value of η, while contractionary technology shocks drive labor productivity lower. We assess the robustness of the results to different values of η. A surprising finding presented in the next section is that the relative contributions of productivity and money are fairly insensitive to different values of the nonneutrality parameter η, although labor productivity is sensitive to this parameter.

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[13] For comparative purposes, we note that a standard predetermined wage model with a 2/3 value for labor in the production function drives down employment 30 percent from a 10 percent unanticipated deflation.

C. The Relative Contributions of Money and Productivity Shocks

Table 5 presents the lower and upper bounds on the contribution of technology shocks and money shocks for different values of the nonneutrality parameter η. We report the average value of the bounds for the 1930–33 period. Our main finding is that the productivity shock is more important than the money shock. For our preferred value of the nonneutrality parameter, the bounds for productivity are a maximum of 89 percent and a minimum of 54 percent. The bounds for money, correspondingly, are a maximum of 46 percent and a minimum of 11 percent. The table also shows that these bounds are not very sensitive to changes in the value of the nonneutrality parameter. The maximum bound for productivity ranges between 82 and 100 percent, and its minimum bound ranges between 45 and 48 percent. (It is interesting to note that a standard sticky wage model generates bounds that are very similar to these.) The midpoints of these bounds suggest that productivity accounts for about 2/3 of the Depression, and monetary shocks account for about 1/3.

The table also reports the contribution of productivity to the Depression for an alternative orthogonalization procedure that removes the component of the productivity shock that is related to deflation. This orthogonalization procedure is interesting because of the considerable attention deflation has received in the literature. This procedure thus adjusts the productivity shock for a possible deflation-related measurement error, such as capacity utilization.[14] This orthogonal component is the residual from a regression of the productivity shock on deflation. We estimate the regression during each year of the Depression. This minimizes the contribution of the orthogonal component relative to running one regression over all four years, and thus provides a conservative estimate of the contribution of this component. The contribution of this orthogonal component of productivity is also large, ranging between 70 and 81 percent for different values of η.

D. Understanding Why Money/Deflation Is Not the Key Factor

The result that money/deflation is not the key driving shock stands in contrast to the conventional wisdom about the Depression. Given the surprising nature of this finding, we

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[14] For example, Bernanke and Parkinson (1991) report that productivity declined in U.S. manufacturing in the Depression, and they interpret that decline as possibly partially due to capacity utilization and/or labor hoarding.

explain why money shocks are not more important. The main reason is that the relationship between deflation and output in the data is much different from that generated by money shocks in the model.

The simplest way to understand this is to first separate the log output fluctuations into 2 components for each year: a cross-country mean component and a country-specific component:

$$y_{it} = \bar{y}_t + \varepsilon_{it},$$

where y_{it} is the log deviation of output in country i in year t from its 1929 value, $\bar{y}_t$ is the cross-country mean log deviation in year t, and ε_{it} is the country-specific component.

Table 6 shows that the country-specific component accounts for most of the output fluctuations. The table also shows that this country-specific component is not systematically related to deflation. The table shows that the correlation between output and deflation, which is the appropriate measure of the relationship between the country-specific component of output and deflation, is negative in 1930 and 1931 and is only significantly positive in 1932. In sharp contrast, money shocks generate a correlation between output deviations and deflation in the model that is almost one. This large difference between the data and the model is the key reason why money/deflation does not account for more of the Depression. In particular, while deflation does account for some of the mean component of the Depression, it is unable to account for the much larger country-specific component. Note that the weak empirical relationship between output and deflation is also the reason deflation accounts for only a small fraction of the Depression in the regression presented in Section 2.

5. Alternative Explanations for the Productivity Shocks

We now ask whether the large contribution of the productivity shocks might be due to some other factors that this version of our model does not capture. We discuss three factors that we consider possibly important in this regard: (1) unmeasured factor utilization, which is a common interpretation of procyclical productivity, (2) allowing for the effects of lagged values of deflation, which may reduce the explanatory power of productivity shocks, and (3) allowing for differences in the nonneutrality of money between countries, which may reduce the importance of productivity shocks.

The first possibility we consider is that the productivity shocks are due to unmeasured factor utilization, specifically, deflation-induced capacity utilization. Our results suggest that the productivity shocks are not just due to deflation-induced capacity utilization. If this *were* the explanation, then the productivity shock would be strongly related to deflation. It is not; recall that Table 5 showed that about 75 percent of the international Depression is accounted for by a productivity shock that is *orthogonal* to deflation. There are other reasons that the productivity shocks are not accounted for just by capacity utilization. In particular, labor productivity fell significantly in some countries, including the United States and Canada. If the productivity shocks were just due to capacity changes, then labor productivity would be higher, not lower.[15] Moreover, the limited explanatory power of deflation in the regression presented in Section 2 suggests that deflation-induced capacity utilization is not the key factor. We have focused here on capacity utilization, rather than labor hoarding, because labor hoarding seems less plausible given the long duration of the Depression. However, some of these same facts have similar implications for labor hoarding explanations, such as the limited explanatory power of regression in Section 2. Additional evidence against the deflation–labor hoarding view is that labor hoarding cannot account for the positive cross-country relationship between real wages and output in the data. If the productivity shocks were due to deflation and labor hoarding, the correlation between real wages and output would be strongly negative. We conclude that if unmeasured factor utilization were quantitatively important, it would be through a shock other than deflation.[16]

The second possibility we consider is if the large contribution of the productivity shock is due to the fact that the monetary nonneutrality operates only through contemporaneous

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[15] This follows from the fact that the capital/labor ratio rises in response to higher real wages as long as there is nonzero substitutability between capital and labor.

[16] While the data indicate that productivity shocks are not plausibly accounted for just by unmeasured factor utilization responding to deflation, it remains an open question how much these factors — if introduced in our model — might change our decomposition. Recent work on the U.S. Depression, however, suggests the decomposition may not change much. Chari, Kehoe, and McGrattan (2002) introduce capacity utilization into a business cycle model for the Depression and find that the contribution of productivity shocks is relatively unchanged. This is due to two offsetting effects: the modified model with capacity utilization reduces the size of the productivity shocks, but the equilibrium response in the modified model to a productivity shock is larger than in the standard model.

deflation in our model.[17] To assess whether lagged values of deflation might be important for our results, we estimated regressions with lagged and contemporaneous deflation terms to see if the possible explanatory power of deflation was larger than in the regression with just contemporaneous deflation presented in Section 2. We therefore considered the following equation:

$$y_{it} = \sum_{j=0}^{n} \alpha_j \pi_{i,t-j} + \varepsilon_{it}.$$

The lagged deflation terms control for the impact of changes in endogenous state variables, such as changes in the capital stock, habit formation, adjustment costs, and so on, as well as other lagged effects of the shocks, such as the possibility of long-lived nonneutralities. We use OLS to estimate models with one and two lags, as well as the contemporaneous term. (Additional lags did not change the explanatory power of the model.)

The explanatory power of the regression did not change much with the addition of these lags. The fraction of squared output change explained in the regression with contemporaneous deflation and two lagged terms is 31 percent, compared to 23 percent in the regression with just the contemporaneous term. This deflation regression has limited explanatory power because even with lagged terms, deflation accounts for very little of the country-specific output component. To see this, we added a constant term to this regression, and we compared the explanatory power from the regression with a constant term and the deflation terms to the explanatory power from the regression with just the constant term.

The regression with a constant and three deflation terms explains 33 percent of squared output change. Moreover, all the deflation coefficients are insignificant at the 5 percent level. The regression with the constant term alone explains 27 percent of squared output change. Thus, adding the three deflation terms to the regression with just the constant adds only 6 percent more explanatory power. Since the constant term controls for mean effects, this

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[17] It is worth noting that as yet there is no canonical, fully articulated model in which lagged values of deflation have large, depressing effects. For example, Christiano, Eichenbaum, and Evans (2001) develop a model in which there is a longer-lived nonneutrality than in standard sticky wage models, but in their model, deflation *increases* output, rather than decreases output.

implies that both contemporaneous and lagged deflation account for very little of the key country-specific output component in this regression.

We next investigate whether the large contribution of the productivity shocks might depend on the parameterization that all countries have the same value for the nonneutrality parameter (η). The best way to pursue this possibility would be based on theory or evidence about cross-country differences that affected the responsiveness of nominal wages to shocks. This information could then be used to choose different values for η. Since we are unaware of any studies along these lines, we first tried to empirically assess differences in the nonneutrality of money across countries by estimating the relative impact of a money shock on output using data from the early 1920s when most of these countries also experienced large deflations. We formed this estimate for each country as the ratio of the change in real output to deflation from this period. We then examined the correlation between these forecasts and our inferred productivity shock and found it to be extremely low. This test suggested that our productivity shocks were not good proxies for country-specific nonneutralities.

We therefore adopted a different approach. We split the 17 countries into two groups based upon whether they had a large or a small fall in output, and we then assigned a different value for the nonneutrality parameter to each group. We chose to split the countries into two groups because the output changes in these countries tend to cluster into two groups: one group has small output changes and the other group has large depressions. Both groups have roughly the same deflation.

The first group includes the six countries that had large depressions: Austria, Canada, Czechoslovakia, France, Germany, and the United States. In 1932, average output in this group was about 25 percent lower than in 1929, with a standard deviation of about 9 percent. We assigned these large depression countries the maximum value of our nonneutrality parameter ($\eta = 0$) so that deflation would have a large, depressing effect. The second group is the remaining 11 countries that had small output changes: Australia, Denmark, Finland, Hungary, Italy, Japan, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom. We assigned the small nonneutrality value ($\eta = 0.75$) to these countries because they had small output declines. In 1932, average output in this group was about 3 percent lower than in 1929, with a standard deviation of about 6 percent.

This ad hoc classification procedure is not based on any theory or evidence about differences in monetary nonneutrality across these countries. Rather, we chose this procedure because it increased the contribution of money shocks by allocating a large nonneutraltiy to the big depression countries and a small nonneutrality to the countries with small downturns. We were surprised that this procedure did not significantly change the decomposition results. Table 7 shows the results. The lower bound for the fraction of output change accounted for by productivity is 47 percent in this experiment, compared to about 52–54 percent in the benchmark experiment. This means that the upper bound for money is only marginally higher in this experiment: 53 percent, compared to about 46–48 percent in the benchmark experiment. The upper bound for productivity in this experiment remains at 88 percent.

Some readers have asked how much of the Depression could be accounted for by monetary shocks rather than productivity if each country had its own optimized nonneutality parameter value, irrespective of any theory or evidence supporting these values. This is not a very interesting question, because this parameterization is not only ad hoc but it also loses the cross-sectional aspect of the international Depression that has motivated the literature. But even with this extreme parameterization, we found that monetary shocks do not account for much of the Depression. We reached this conclusion by estimating a modified version of (1) in which there are county-specific coefficients for the deflation variable, and since we do not have productivity variables for each country, we use proxies for productivity by including a country-specific constant term in the regression:

$$y_{it} = \alpha_i + \gamma_i \pi_{it} + \varepsilon_{it}.$$

Almost all of the explanatory power in this regression is due to the constant terms, rather than deflation. The deflation slope coefficients are not significantly different from zero. The R^2 is almost the same with deflation omitted from the equation as when all the terms are included. The R^2 is 0.84 with all the deflation terms, and is 0.78 without any deflation terms. These results suggest that country-specific deflation responses provide almost no incremental information about the Depression.

This discussion suggests that the large contribution of productivity shocks is not significantly affected by these alternative factors. The findings also have implications for those readers whose reaction to these results is to wonder whether there are plausibly parameterized deflation-driven models in which deflation is the dominant factor and productivity is unimportant. Addressing this question is beyond the scope of this paper, but our findings do highlight the challenges that pure deflation-driven models face. In particular, a key challenge is that neither deflation nor lagged deflation are systematically related to output.

A. Comparing Our Findings to the Literature

We now compare our findings to those in the literature, though this literature differs in important ways. One strand of the literature uses general equilibrium models, but these studies typically analyze a single country, rather than a cross section, and typically do not conduct a shock decomposition analysis. With this in mind, we find that our results are largely consistent with the results from these single-country studies, which cover 5 of the 17 countries analyzed here. These include the United States (Cole and Ohanian (1999, 2000), Chari, Kehoe, and McGrattan (2002), and Bordo, Erceg, and Evans (2000)), Canada (Amaral and MacGee (2002)), Germany (Fisher and Hornstein (2002)), France (Beaudry and Portier (2002)), and Italy (Perri and Quadrini (2002)). Seven of these nine papers study productivity shocks and generally find a role for this shock, though only Chari, Kehoe, and McGrattan conduct a shock decomposition. Few of these papers study the role of monetary shocks. Cole and Ohanian (2001), Amaral and MacGee, and Chari, Kehoe, and McGrattan suggest that money played some role but was not the major factor. The one paper that argues that deflation–sticky wages is the dominant factor for the United States is Bordo, Erceg, and Evans (2000). Their findings differ from ours and from Chari, Kehoe, and McGrattan's findings because their one-shock model abstracts from productivity shocks. Consequently, their model counterfactually predicts very high labor productivity during the Depression. It is likely that their findings would have been similar to ours and those of Chari, Kehoe, and McGrattan if they had included a productivity shock, as the model economy that they use is similar to the one used by us and Chari, Kehoe, and McGrattan.

The second strand of the literature is cross-country regression studies, including Bernanke (1995), Bernanke and Carey (1996), Eichengreen and Sachs (1985), and Choudhri and Kochin

(1980). This literature is really not comparable, because these studies use a very different methodology. They focus on a different issue, which is the recovery from the Depression rather than the causes of the Depression. They do not include productivity shocks. They use different measures of output and prices, and they include post-Depression (post-1933) data in the analysis. These papers argue that monetary forces operating through sticky wages are a key factor for recovery from the Depression, and they report a negative relationship between industrial production (IP) and a nominal wage rate deflated by a wholesale price index (WPI).[18]

To try to compare our findings to those in this literature, it is necessary to first sort out the difference between the positive wage-output correlation reported in this paper and the negative relationship reported in these other papers. There are two issues: the measurement of the real wage and the years covered by the analysis. Regarding measurement, this literature uses the wholesale price index to deflate the nominal wage, but this is not the right price index to use because the sticky-wage theory requires that the wage be deflated by the price of final output, but the wholesale price index is based primarily on a bundle of raw input prices.[19] Regarding the years of observation, our analysis focuses solely on the Depression years. This other literature mixes data from part of the Depression and from the post-Depression period. (For example, Bernanke's study omits the first year of the Depression (1930), and includes two post-Depression years (1934–35).

We previously established that the correlation between real GDP and the wage deflated by the GDP deflator is largely positive in the Depression (1930–33). It also turns out that the correlation between IP and the wage deflated by the WPI is largely positive during this period (see Table 8). The correlation between real GDP and the wage deflated by the deflator changes after 1933, becoming negative. A similar pattern emerges for IP and the wage deflated by the WPI. This change in the correlation sign between real GDP and the wage relative to the deflator raises the possibility that monetary forces working through sticky wages may

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[18] Choudhri-Kochin do not focus on the relationship between output and real wages, but on the relationship between output and prices for a small group of countries. Our comments below about output and real wages also apply to output and prices in this paper.

[19] Moreover, the composition of wholesale indexes differs substantially across countries, which further complicates cross-country comparisons.

have been more important for the recovery from the Depression rather than as a cause of the Depression. It should be noted that this evidence does not establish the importance of this factor for the recovery because of the omission of other variables, including productivity and the large government policy changes that were adopted in many countries at the end of the Depression. As discussed in Section 2, addressing the relative importance of monetary and other shocks for the post-Depression period would require a parameterized general equilibrium model that would go well beyond the scope of this paper. We therefore conclude that the cross-country regression literature does not have implications for our decomposition results.

6. The Characteristics of the Shocks

We now examine the shocks for our preferred parameterization of $\eta = -0.50$. Table 9 reports some statistics on both the money and productivity shocks. The mean money and productivity shock is negative in every year except the first year, 1930. The reason for the positive 1930 productivity shock is that there was a large deflation in 1930, but average output fell only slightly in that year (see Table 1). Under this parameterization, the actual productivity deviation, z, is negative in every year after 1930, despite the residual effects of the 1930 positive productivity shock. This is not true under parameterizations with higher degrees of the nonneutrality of money.

It is interesting to note that the coefficient of variation (the standard deviation divided by the mean) of the productivity shock tends to be larger than that of the money shock, much as the coefficient of variation of output change is larger than the coefficient of variation of deflation (see Table 1). Thus, the large variation in output due to the large idiosyncratic component described in the preceding section is largely being generated by the productivity shock.

The final panel of the table shows that the shocks are not highly correlated for most of the Depression. This means that most of the difference between the minimum and maximum bounds is due to the allocation of the nonzero means of the shocks, rather than the covariance between the shocks. The fact that the covariance is small in most years provides further support for the independent contribution of the productivity shock.

7. Comparing the Model to the Data

To further assess the plausibility of our results, we next compare the model predictions to the actual data. We focus on comparing actual productivity with productivity from the model. This is very useful because we have aggregate productivity for 7 of the 17 countries (TFP for Canada, France, Germany, the United Kingdom, and the United States, and labor productivity for Australia and Japan). This analysis thus provides a useful diagnostic for our model. If the model is successful, there should be a close relationship between productivity in the model and actual productivity. We find a very close relationship between these variables.

Figure 4 summarizes these data by plotting the actual productivity in each country and each year against the corresponding productivity in the model. The figure clearly shows a strong, systematic relationship between the actual and model productivity. The correlation between these variables is about 0.91. Appendix table A4 shows these data. The fact that the model constructs productivity shocks that line up closely with actual productivity means that the model is accurately decomposing the fraction of output change into changes due to input and changes due to productivity.

Our next productivity comparison goes beyond these 7 countries by examining productivity in the model and the data for countries in which we have labor productivity in the industrial sector. We have industrial labor productivity for 14 of the 17 countries (all the countries except Czechoslovakia, Denmark, and Switzerland).[20] We therefore calculate the correlation between the log-deviation in total factor productivity and labor productivity in the model between 1929 and 1932 for the 11 countries for which have these data, and between 1930 and 1932 for the 14 countries for which we have these data. These correlations are fairly high, 0.63 and 0.60, respectively, for total factor productivity and 0.59 to 0.35, respectively, for labor productivity. To benchmark these correlations, note that they are close to the postwar cyclical correlations between these variables (0.72 for TFP and 0.56 for labor productivity).[21] These comparisons provide further support for our output decomposition

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[20] For Austria, France, and Germany, data limitations allowed us to use only changes from their 1930 levels.

[21] The reported correlations are for HP filtered data where the filtering parameter was set to 400. We also computed these correlations for a filtering parameter of 6.25, but the results were very similar: 0.58 and 0.78, respectively. We focus on the values generated by the larger filtering parameter since we are not detrending the data for the Great Depression.

results.

Our next comparison is between the real wage rate in the model and the real wage rate in the data. This comparison is more complicated because of a number of measurement problems. These include (1) cyclical compositional changes among workers, (2) the wage rate in the model is for the aggregate economy, but the measured wage rate is just for the industrial sector, (3) the size and composition of the industrial sectors differ across countries, (4) wage survey methodologies may differ across countries, and (5) data transcription errors may be large for some countries.[22] We are able to make some adjustments for the first two of these problems but unfortunately not for the others

Regarding compositional changes in workers, the average quality of workers tends to rise during depressions, because the least experienced and least productive employees are typically the first to be laid off. We have addressed this measurement problem by compositionally adjusting the wage rate in the model, using the postwar U.S. estimates of cyclical labor composition bias produced by Solon, Barsky, and Parker (1994).[23] Regarding the issue that the measured wage is only for the industrial sector of the economy, we provide a benchmark for interpreting the relationship between the model wage and the actual industrial wage by showing the relationship between these variables during postwar U.S. business cycles. We therefore calculated the cyclical correlation between industrial wages and the aggregate wage using postwar U.S. HP-filtered data and obtained a value that ranges between 0.48 and 0.8, depending on the value of the smoothing parameter.[24] The correlation in three of the four Depression years is reasonably high, ranging from 0.53 to 0.67, with a low of 0.26 in 1933, and is comparable to the postwar U.S. values, particularly given that the Depression wage measures may have significantly more measurement error.

The final comparison we can make is between the money supply in our model and

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[22] Regarding this latter measurement issue, we found that the nominal wage rate in some countries is constant for a sequence of years, which will tend to lead to positive measurement error during deflationary periods.

[23] The log-deviations in model real wages, w, were generated according to $w^* = w - 0.49 * n$, where n, the employment share, is serving as a proxy for unemployment. We compositionally adjust the model wages since we have measures of employment in the model for all of our countries.

[24] The correlation is 0.48 for a smoothing parameter of 400 and is 0.84 for a smoothing parameter of 6.25. The U.S. series are average hourly earnings for manufacturing and average hourly earnings for the private economy, from 1955 to 2003.

that in the data. This comparison is complicated because there is some evidence of money demand shocks during the Depression (see Christiano, Motto, and Rostagno (2004) and Field (1984)), but our model abstracts from this feature. This means that even though our model matches the price level, there may be a difference between the money supply in the model and in the data.[25] Despite abstracting from money demand shocks, we find a correlation between the model money supply and the actual money supply that ranges between 0.5 and 0.7 for three of the four Depression years. (The correlation is about 0.3 in 1930.)

Overall, we find that these comparisons between the model and the data — particularly for productivity — suggest our decomposition results are plausible. We now turn to learning more about these productivity shocks.

8. Productivity Shocks and the Stock Market

The productivity shocks we feed in the model have a large persistent component, which means that once a negative shock is realized, it is expected to continue into the future. This stands in contrast to the existing view that the persistence of the Depression was due to a sequence of transitory surprises (see Lucas in Klamer (1983)). These alternative views about the persistence of the shock have very different implications for the Depression, and we now try to shed some light on this persistency issue. If a persistent shock is key for the Depression, then we would expect that economic agents recognized this. This section explores this possibility by correlating real stock prices — which are forward looking — with future productivity shocks in our model. We will show a very high correlation between lagged stock prices and the productivity shock. Given this high correlation, we will then use this new information to provide an independent assessment of the relative contribution of productivity shocks to the Depression.

The correlation between real industrial stock prices, lagged one year (measured as log deviations from 1929), and TFP from our model is 0.75. To benchmark this value, we

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[25] Note that we could add a money demand shifter in this model by making the cash goods preference parameter a random variable. To specifically see how our model that abstracts from this feature would tend to generate a money supply that differed from the actual money supply, suppose there is a shock to money demand that lowers the price level by 1 percent. Note that our model without the money demand shock would generate this lower price level through a negative money supply shock. Thus, the money supply shocks that our model requires will reflect both money supply and money demand shocks, and thus will tend to differ from observed changes in the money supply.

compare it to the cyclical correlation between lagged real stock prices and TFP in postwar annual U.S. data (1951–2003), which is 0.38 for the Dow Jones Industrials. Thus, there is a much stronger correlation between the stock market and future productivity during the Depression than in postwar cyclical fluctuations.[26]

This high correlation between the lagged stock market and productivity suggests that these productivity shocks were perceived to be very persistent. We examine the economic significance of this implication by extending a model developed by Aiyagari (1994) to say more about the perceived persistence of the productivity shock and to provide additional evidence on the relative contribution of productivity shocks to the Depression. Aiyagari used his model to measure the contributions of productivity shocks to postwar U.S. fluctuations, and we extend his model by including the stock market. This augmented Aiyagari model will use the correlation between the lagged stock market and productivity to show (1) that the high correlation is indeed consistent with a highly persistent productivity process, and (2) that our original estimate that 2/3 of the Depression is due to productivity shocks is very conservative.

Aiyagari's original model has three log-linearized equations: a standard production function (that abstracts from capital); an equation governing the evolution of labor in response to two shocks — productivity and another labor shifter; and the autoregressive process for the productivity shock. These equations are

$$(6) \quad y = z + (2/3) * n,$$

$$(7) \quad n = \gamma z + \omega,$$

$$(8) \quad z = \rho_z z_{-1} + \varepsilon.$$

In these equations, y is the log of output, z is productivity, n is labor, and ω is the other shock driving labor. The parameter ρ_z governs the autocorrelation of productivity. The shocks ε and ω are independent, mean zero, normally distributed random variables. Note

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[26] We HP filtered the postwar U.S. time series to isolate the cyclical fluctuations and thus make the series reasonably comparable to the Depression observations, which are log changes from their 1929 values.

that this framework is consistent with our misperceptions model. Abstracting from capital, both setups share the same production function, the same law of motion for the productivity shock, and the same equation that governs the evolution of labor.

Aiyagari chose the variance of ω and the value of the parameter γ so that the model matches (i) the observed correlation between cyclical labor productivity and cyclical output, and (ii) the observed variance of the ratio of cyclical hours to cyclical output. This parameterization of Aiyagari's model implied that productivity shocks account for about 3/4 of postwar U.S. fluctuations.

We extend his model to include an equation for the value of the stock market, which will allow us to use the correlation between lagged stock prices and productivity. In addition to equations (6)–(8), we add the following stock market equation:

$$s = \delta z + \beta \omega + \xi.$$

The variable s is the value of the stock market, and ξ is a noise term. This equation would arise in an augmented version of our model in which there are adjustment costs to investment and noise movements in stock prices. These noise movements in stocks could include time variation in risk premia or other factors that do not affect output, as well as measurement error. The innovations ε, ω, and ξ are i.i.d. processes.

We set $\rho_z = 0.90$. We choose the other six parameters — standard deviations of ε, ω, and ξ, and the coefficients γ, δ, and β — to match six moments from the postwar period: the variances and covariances of postwar HP filtered real GDP, employment, and the real value of the Dow Jones Industrials index.[27] Given these parameter values, the productivity shock accounts for 64 percent of postwar output fluctuations, and the model implies a correlation of 0.40 between the lagged stock market and productivity for the postwar U.S. economy. This is very close to the actual correlation of 0.38 between these variables for the postwar period. This suggests that the observed postwar correlation between lagged stock prices and productivity is consistent with productivity accounting for about 2/3 of cyclical fluctuations.

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[27] The parameterization is given by $\sigma_\varepsilon = 0.0064$, $\sigma_\omega = 0.0220$, $\sigma_x = 0.1066$, $\gamma = 0.5056$, $\delta = 3.5877$, and $\beta = 0.3671$.

How much would we need to change the model parameters in order to understand the 0.75 correlation between these variables? Equation (9) shows how the correlation between lagged stock prices and productivity depends on the value of ρ_z and the variance of the three shocks:

$$(9) \quad corr(z_t, s_{t-1}) = \frac{\delta \rho_z \sigma_z^2}{\sigma_z \sqrt{\delta^2 \sigma_z^2 + \beta^2 \sigma_\omega^2 + \sigma_\xi^2}},$$

where $\sigma_z^2 = \sigma_\varepsilon^2/(1-\rho_z^2)$. This equation shows how increases in the persistence of the productivity process (ρ_z), decreases in the amount of stock market noise (σ_ξ), and/or an increase in the variability of productivity shocks (σ_ε) or a decrease in the variability of the labor shifter (σ_ω) affect the correlation between lagged stock prices and productivity. We now vary these parameters to see what changes are required to increase the correlation from 0.40 (the postwar correlation) to 0.75 (the Depression correlation). In all of these experiments, we keep the variability of y fixed.

We first change ρ_z (and simultaneously reduce σ_ε to keep σ_z fixed, which also keeps the variance of output fluctuations fixed). We find that even raising ρ_z to 1 generates a correlation of only 0.44, while if we lower it to 0.5 the correlation falls to 0.22. Thus, higher persistence alone cannot come close to accounting for the high Depression correlation. Lower persistence, however, makes it even more difficult to account for this higher correlation.

We next reduce the variance of the noise term, keeping all other parameter values equal to their benchmark values, to generate the 0.75 correlation. By reducing the relative variance of the noise term, this experiment makes the stock market a more accurate forecaster of the productivity shock. We find that the relative variance of the noise term must fall by more than 90 percent to generate the 0.75 correlation. (We stress that this is a relative reduction in the variance of the noise term, because the values of the other parameters are fixed. Thus, this does not imply that the variance of the noise fell in absolute terms in the Depression, because the variance of output was much higher during this period.) Thus, accounting for the higher correlation though this channel requires that the noise term become relatively very small. In interpreting our findings, note that since the variation in y rose enormously, it was not necessary for the stock market noise to actually fall, it was only necessary for it not to rise nearly as much as the variability of output. For example, the cross-sectional variance of output during the Great Depression in 1932 was roughly 20 times as big as the variance of output around the HP trend in the postwar U.S. data that we calibrated our model to.

We next consider changing the variance of the productivity shock (σ_ε) while we simultaneously reduce the variance of the other shock (σ_ω) in order to keep the variance of output fixed. We find that if we raise σ_ε so that the contribution of the productivity shock to the variance of output is 100 percent, the correlation rises to only 0.47. In contrast, if we reduce the contribution of productivity shocks so that they account for only 1/3 of the Depression, the correlation falls to 17 percent. This indicates that while raising the share of productivity in the variability of output can help account for the observed correlation, it cannot do it alone. It also highlights the tension involved in accounting for the correlation under the assumption that productivity's contribution to the Depression was small.

These quantitative experiments indicate that the Great Depression lagged stock price–productivity correlation was extreme. Achieving this correlation requires a relatively small noise component and a persistent productivity shock that accounts for at least 2/3 of the Depression. The stock market thus provides independent evidence that the productivity shock was an important contributing factor to the Depression.

9. What Factors Are Driving these Productivity Shocks?

We now explore what deeper factors might be driving these productivity shocks. We do this by correlating the productivity shock with other country-specific variables. Our choice of variables is based on the extent to which theory suggests they may shed light on the shocks, and also on data availability. We consider four variables. Two variables are related to international transactions: the size of each country's trade share (measured as a fraction of GDP in 1929) and the value of the real exchange rate (measured as the change in the real exchange rate relative to 1929). The other two variables are the size of each country's agricultural sector in 1929 and Bernanke and James' (1990) measure of banking panics/distress.[28] The international variables are interesting because in open economy models, shocks to interna-

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[28] This banking panic variable is a 0,1 variable, in which the authors subjectively assess whether a country is having a panic or not. The authors construct this variable each month, so the annual measure is the fraction of the year a country had a panic.

tional trade in intermediate inputs will appear as a productivity shock in a closed economy model that abstracts from intermediate inputs. The banking panic variable is interesting for a similar reason; in models in which financial services are intermediate inputs, a reduction in financial services will also appear as a productivity shock in a technology that abstracts from these inputs. The size of the agricultural sector is interesting because it can shed light on the extent to which the Depression was largely an industrial phenomenon.

Table 10 shows these correlations for 1932, which is near the trough for most of the countries. The most promising variables that seem to merit future study are the size of the agricultural share, the real exchange rate, and the banking panic. (Surprisingly, we found a very small correlation between productivity and the size of the trade share.)

The positive correlation between the size of the agricultural sector and productivity means that the Depression was more severe for the highest industrialized countries, suggesting that the shock originated in, or more significantly affected, industrial economic activity rather than agricultural activity. The correlation between the real exchange rate and the productivity shock means that countries that had higher productivity shocks had lower real exchange rates. There are different interpretations of this correlation, because the real exchange rate is an endogenous variable. One possible interpretation might follow along the lines of Eichengreen and Sachs (1985), who argue that interwar changes in the real exchange rate are driven by devaluations which increased demand. Pursuing this interpretation would be of interest for future work and would require connecting this demand-induced channel to productivity. (This correlation is somewhat sensitive to timing, however, because the correlation is in the 0.2–0.3 range in 1931 and 1933.) The correlation between the banking panic variable and productivity indicates that countries with more severe banking panics had negative productivity shocks. This correlation is somewhat sensitive, however, to the inclusion of the United States and Austria; the correlation between this variable and productivity is about -0.3 without these two countries in the sample. Future work along these lines could be aimed at further quantification of banking and perhaps more broadly, financial market shocks, and at developing models in which financial shocks have large and systematic effects on productivity.

10. Summary and Conclusion

This paper presented a dynamic, stochastic general equilibrium study of the causes of the international Great Depression, the 1930–33 period in which many countries experienced macroeconomic downturns. We developed a fully articulated model to assess the relative contributions of monetary/deflation shocks, which are the most commonly cited shocks for the Depression, and productivity shocks. In our model, deflation reduces output through imperfectly flexible wages, which is the key channel stressed in the literature. This mechanism is driven by an information imperfection in our model that allows us to easily vary the impact of a money shock by parameterizing the size of the nonneutrality of money.

We used the model to evaluate the fraction of output change accounted for by each of these shocks for 17 countries between 1930 and 1933. Because of data availability, our analysis faced some challenges in terms of identifying the shocks. We therefore developed a new analytical procedure in which we constructed monetary and productivity shocks so that the model completely accounted for output and price changes in the Depression. Given these constructed shocks, we also developed a new accounting procedure that constructs decomposition bounds for the contribution of nonzero-mean shocks.

Our main finding is surprising: productivity is the dominant shock, accounting for about 2/3 of the Depression, with the monetary shock accounting for about 1/3. The productivity shock is also largely orthogonal to deflation. We tested the model by comparing the productivity shocks in the model to actual productivity changes in seven countries for which we have productivity data. For our preferred calibration of the nonneutrality of money, we found that the constructed shocks and actual productivity changes are extremely similar, with a correlation of 0.91. We also concluded that productivity was an important contributing factor, even considering capacity utilization, labor hoarding, and differences in the nonneutrality of money across countries. The main reason monetary/deflation shocks are unimportant is that there is no systematic correlation between deflation and output in the data. Specifically, most output fluctuations in our panel of countries are country-specific, and this large country-specific component is unrelated to deflation. This suggests that linear models driven exclusively by deflation shocks will not account for the bulk of the international Depression.

We also found a very high correlation between lagged stock prices and the productivity shocks, much higher than observed during U.S. postwar fluctuations. We used a version of Aiyagari's (1994) model to interpret this correlation and found that the stock market evidence is also consistent with a very persistent productivity process driving the international Great Depression. Our finding that a highly persistent productivity shock is the key factor stands in contrast to the conventional view that a continuing sequence of unexpected deflation shocks was the major cause of the Depression.

What are these productivity shocks? Given that we did not find them plausibly explained by capacity utilization or labor hoarding, we correlated the shocks with other variables to learn more about them. We found some support for the view that the shocks hit the industrial sector, rather than the agricultural sector, and that the shocks may be related to financial panics and changes in the real exchange rate. Future research should develop and analyze theories that can shed light on what these productivity-like shocks might be standing in for in our simple growth model. Possibilities include breakdowns in borrowing/lending relationships and credit (see Bernanke (1983)), large decreases in organization/information capital (see Ohanian (2001)), or government policy interventions that affected efficiency, such as Herbert Hoover's jawboning of U.S. firms to practice work sharing rather than use layoffs during the downturn (see Cole and Ohanian (2001)).

The key point is that any candidate factor cannot be a shock that affects only inputs. Rather, a candidate factor must work so that it looks like a productivity shock in a simple neoclassical production function, and the factor must be largely uncorrelated with deflation.

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11. Appendix

A. Data

The primary sources of the data are from B.R. Mitchell's International Historical Statistics. These are available for (i) Europe, (ii) Africa, Asia, and Oceania, and (iii) the Americas. This includes the majority of the data on real and nominal GDP, industrial wages, production and prices, as well as the agricultural and industrial shares of GDP. Data on the stock market and gold parities come from the League of Nations Statistical Yearbooks from 1933 to 1940. Where available, we have used the latest official publications of historical data. This includes the data for Australia, Canada, Japan, the United Kingdom, and the United States. We have also endeavored to use the latest revisions of data where available. This includes the data for France, Germany, Italy, and Sweden. Listed bellow are the data sources by country. Unless otherwise indicated, the data used are from B.R. Mitchell and the League of Nations.

Australia

Nominal and real GDP, GDP deflator: Butlin, M.W., 1977, A Preliminary Annual Database 1900/01 to 1973/74, Research Discussion Paper 7701, Reserve Bank of Australia.

Industrial production, price and wage indices: *Australian Historical Statistics* (Wray Vamplew, ed.), New York: Cambridge University Press, 1987.

Canada

Nominal and real GDP, GDP deflator, industrial production and wages: Statistics Canada, Historical Statistics (SC-HS).
(http://www.statcan.ca/english/freepub/11-516-XIE/sectiona/toc.htm)

France

Nominal and real GDP, GDP deflator, industrial production: Beaudry, P., and Portier, F., 2002, The French Depression in the 1930s. *Review of Economic Dynamics* 5 (January): 73–99.

Note that the data provided by Beaudry and Portier were derived from data in Villa, P., 1993, *Une Analyse macro-Economique de la France au XXieme Siecle*. Paris: Presses du CNRS.

Germany

Nominal and real GDP, GDP deflator, industrial wages: Fisher, J., and Hornstein, A., 2002, The Role of Real Wages, Productivity, and Fiscal Policy in Germany's Great Depression, 1928–1937, *Review of Economic Dynamics* 5 (January): 100–127.

Italy

Nominal and real GDP, GDP deflator, industrial wages, production, and prices: Perri, F., and Quadrini, V., 2002, The Great Depression in Italy: Trade Restrictions and Real Wage Rigidities, *Review of Economic Dynamics* 5 (January): 128–151.

Note that the data provided by Perri and Quadrini were based on data in (i) Ercolani, P., 1978, Documentazione Statistica di Base in (G. Fua, ed.), *Lo sviluppo Economico in Italia*, 3: 388–472, and (ii) Rey, G., 1991, *I Conti Economici dell'Italia*, Bari: Laterza.

Japan

Industrial prices and wages: (i) Hundred-Year Statistics (100 Years) of the Japanese Economy, 1966, Statistis Department, Bank of Japan, and (ii) Supplement to Hundred-Year Statistics of the Japanese Economy (English translation of footnotes).

Sweden

Real GDP, GDP deflator, industrial production, prices, and wages: John Hassler's data set at (http://hassler-j.iies.su.se/SWEDATA/).

Note that the data used from Hassler's data set were derived from Krantz, O., and Nilsson, C-A., 1975, Swedish National Product, 1861–1970, Lund.

United Kingdom

Nominal and real GDP, GDP deflator, industrial production, prices, and wages: Feinstein, C.H., 1972, National Income, Expenditure and Output of the United Kingdom, 1855–1965, Cambridge University Press.

United States

Nominal and real GDP, GDP deflator for 1919–29: Romer, C., 1989, The Prewar Business Cycle Reconsidered: New Estimates of Gross National Product, 1869–1908.

Nominal and real GDP, GDP deflator for 1929–40: Bureau of Economic Analysis, National Income and Product Accounts, Table 1.2B and Fixed Asset Tables, Table 1.2.

Industrial production: Board of Governors of the Federal Reserve Bank, series FRB B50001.

Industrial prices: *Historical Statistics of the United States: Colonial Times to 1970*, part 1, (HSUS), U.S. Bureau of the Census.

Industrial wages: Hanes, C., 1996, Changes in the Cyclical Behavior of Real Wage Rates, 1870–1990, *Journal of Economic History*.

B. Characterizing the Equilibrium of the Misperceptions Model

We have the following set of equations:

1. $Z_t K_t^{\theta} N_t^{1-\theta} = C_t + K_{t+1} - (1-\delta)K_t$

2. $\bar{\tau} e^{\tau_t} = P_t C_{1t}$

3. $-\phi/(1-N_t) + W_t E\{\lambda_t | W_t, \hat{S}_t\} = 0$

4. $[\alpha C_{1t}^{\sigma} + (1-\alpha)C_{2t}^{\sigma}]^{-1} \alpha C_{1t}^{\sigma-1} - (\lambda_t + \psi_t)P_t = 0$

5. $[\alpha C_{1t}^{\sigma} + (1-\alpha)C_{2t}^{\sigma}]^{-1} (1-\alpha) C_{2t}^{\sigma-1} - \lambda_t P_t = 0$

6. $\beta E_t\{\lambda_{t+1} + \psi_{t+1}\}/T_t - \lambda_t = 0$

7. $\beta E_t \left\{\lambda_{t+1}\left(R_{t+1} + P_{t+1}(1-\delta)\right)\right\} - \lambda_t P_t = 0$

8. $P_t Z_t \theta (N_t/K_t)^{1-\theta} = R_t$

9. $P_t Z_t (1-\theta)(K_t/N_t)^{\theta} = W_t$

10. $C_{1t} + C_{2t} = C_t$.

The next step is to log-linearize the set of equations we're solving. We denote the log deviations in lowercase. Note that λ's log deviation is given by $\hat{\lambda}$ and ψ's log-deviation is given by $\hat{\psi}$. We denote by the unhatted variables the values around which we're taking our approximation.

The steady state of our model is therefore determined by

1. $ZK^{\theta}N^{1-\theta} = C + \delta K$

2. $\bar{\tau} = PC_1$

3. $-\phi/(1-N) + \lambda W = 0$

4. $[\alpha C_1^{\sigma} + (1-\alpha)C_2^{\sigma}]^{1/\sigma-1}\,\alpha C_1^{\sigma-1} - \lambda\bar{P} - \psi\bar{P} = 0$

5. $[\alpha C_1^{\sigma} + (1-\alpha)C_2^{\sigma}]^{-1}\,(1-\alpha)C_2^{\sigma-1} - \lambda\bar{P} = 0$

6. $\beta(\lambda + \psi)/T - \lambda = 0$

7. $\beta(\bar{R} + P(1-\delta)) - P = 0$

8. $PZ\theta(N/K)^{1-\theta} = \bar{R}$

9. $PZ(1-\theta)(K/N)^{\theta} = W$

10. $C = C_1 + C_2$

11. $Z = 1$

12. $T = 1$.

The deviations of our model around this steady state are determined by the following system of equations:

1. $\hat{z}_t + \theta\hat{k}_t + (1-\theta)\hat{n}_t = \dfrac{C}{Y}\hat{c}_t + \dfrac{K}{Y}(\hat{k}_{t+1} - (1-\delta)\hat{k}_t)$

2. $\hat{\tau}_t = \hat{p}_t + \hat{c}_{1t}$

3. $-\hat{n}_t N/(1-N) + \hat{w}_t + E\{\hat{\lambda}_t | \hat{w}_t\} = 0$

4. $0 = \left\{(\sigma - 1) - \left[\alpha C_1^\sigma + (1-\alpha)C_2^\sigma\right]^{-1} \alpha C_1^\sigma \sigma\right\} \hat{c}_{1t}$
   $- \left\{\left[\alpha C_1^\sigma + (1-\alpha)C_2^\alpha\right]^{-1} (1-\alpha) C_2^\sigma \sigma\right\} \hat{c}_{2t}$
   $- \hat{p}_t - \dfrac{\lambda P \hat{\lambda}_t + \psi P \hat{\psi}_t}{\lambda P + \psi P}$

5. $0 = -\left\{\left[\alpha C_1^\sigma + (1-\alpha)C_2^\sigma\right]^{-1} \alpha C_1^\sigma \sigma\right\} \hat{c}_{1t}$
   $+ \left\{(\sigma - 1) - \left[\alpha C_1^\sigma + (1-\alpha)C_2^\sigma\right]^{-1} (1-\alpha) C_2^\sigma \sigma\right\} \hat{c}_{2t}$
   $- (\hat{\lambda}_t + \hat{p}_t)$

6. $\beta E\{\lambda\hat{\lambda}_{t+1} + \psi\hat{\psi}_{t+1}\} - \bar{\tau}\lambda(\hat{\lambda}_t + \hat{\tau}_t) = 0$

7. $E\left\{(\beta R/P)\hat{r}_{t+1} + \hat{\lambda}_{t+1} + \beta(1-\delta)\hat{p}_{t+1})\right\} - (\hat{\lambda}_t + \hat{p}_t) = 0$

8. $\hat{p}_t + \hat{z}_t + (1-\theta)(\hat{n}_t - \hat{k}_t) = \hat{r}_t$

9. $\hat{p}_t + \hat{z}_t + \theta(\hat{k}_t - \hat{n}_t) = \hat{w}_t$

10. $C_1\hat{c}_{1t} + C_2\hat{c}_{2t} = C\hat{c}_t$

11. $\hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_t^z$

12. $\hat{\tau}_t = \rho_\tau \hat{\tau}_{t-1} + \varepsilon_t^\tau$.

C. Solving the Model via the Method of Undetermined Coefficients

In this case we define the state vector to be $s_t = (\hat{k}_t, \hat{z}_{t-1}, \hat{\tau}_{t-1}, \varepsilon_t^z, \varepsilon_t^\tau)$ and assume that our controls can all be written as a linear function of the state. Thus, we define our controls as $d_t = (\hat{k}_{t+1}, \hat{n}_t, c_t, \hat{p}_t, \hat{w}_t, r_t, \hat{\lambda}_t, \psi_t)$, and our system has the form $d_t = Ds_t$. For example, $c_t = D_c s_t$ and $\hat{k}_{t+1} = D_k s_t$. We also want to define the selector matrices for $\hat{k}_t$, $\hat{z}_t$, and $\hat{\tau}_t$:

$$I_k = [1\ 0\ 0\ 0\ 0]$$

$$I_z = [0\ \rho_z\ 0\ 1\ 0]$$

$$I_\tau = [0\ 0\ \rho_\tau\ 0\ 1]$$

and the forecasting matrix H for s_{t+1} :

$$H = \begin{bmatrix} D_k \\ I_z \\ I_\tau \\ 0_5 \\ 0_5 \end{bmatrix}.$$

Handling the expectational equation:

Equation (3) involves an expectational term. Given that $\hat{\lambda}_t = D_\lambda s_t$, $\hat{w}_t = D_w s_t$, and that all but the last two terms of the state vector are common knowledge at the beginning of the period, the inference problem for the workers is to extract a forecast of

$$D_{\lambda 4}\varepsilon_t^z + D_{\lambda 5}\varepsilon_t^\tau$$

from observing

$$D_{w4}\varepsilon_t^z + D_{w5}\varepsilon_t^\tau.$$

This is a standard signal extraction problem, and the solution is given by

$$E\{D_{\lambda 4}\varepsilon_t^z + D_{\lambda 5}\varepsilon_t^\tau | D_{w4}\varepsilon_t^z + D_{w5}\varepsilon_t^\tau\} = \eta\left(D_{w4}\varepsilon_t^z + D_{w5}\varepsilon_t^\tau\right)$$

$$\eta = \frac{E([D_{\lambda 4}\varepsilon_t^z + D_{\lambda 5}\varepsilon_t^\tau]\,[D_{w4}\varepsilon_t^z + D_{w5}\varepsilon_t^\tau])}{E([D_{w4}\varepsilon_t^z + D_{w5}\varepsilon_t^\tau]^2)} = \frac{D_{\lambda 4}D_{w4}\sigma_z^2 + D_{\lambda 5}D_{w5}\sigma_\tau^2}{(D_{w4})^2\sigma_z^2 + (D_{w5})^2\sigma_\tau^2}.$$

Hence,

$$E\{\hat{\lambda}_t|\hat{w}_t\} = [D_{\lambda 1}, D_{\lambda 2}, D_{\lambda 3}, \eta D_{w4}, \eta D_{w5}] * s_t.$$

D. Characterizing the Equilibrium of the Sticky Wage Model

In this model each type of household sets their nominal wage given $\bar{S}_t$. The model is otherwise identical to the misperceptions model. We therefore present only the optimization problems and equations that differ.

Producer's Problem: Because households are setting their wage, we include the CES labor aggregate in the firm's problem to derive the firm's labor demand schedule for each type of labor. The profit maximization problem is given by

$$\max_{K_t^d, N_t^d} P_t Z_t (K_t^d)^\gamma \left(\left[\int_0^1 N_t^d(i)^\theta di \right]^{1/\theta} \right)^{1-\gamma} - \int_0^1 W_t(i) N_t(i) di - R_t K_t.$$

The first-order conditions for this problem are

$$\begin{aligned} P_t Z_t \gamma (N_t/K_t)^{1-\gamma} &= R_t \\ P_t Z_t (1-\gamma)(K_t/N_t)^\gamma \left[\int_0^1 N_t(i)^\theta di \right]^{(1-\theta)/\theta} \frac{1}{\theta} N_t(i)^{\theta-1} \theta &= W_t(i), \end{aligned}$$

where

$$N_t = \left[\int_0^1 N_t^d(i)^\theta di \right]^{1/\theta}.$$

This second equation yields the following labor demand function for labor of type i :

$$N_t^d(W_t(i)) \equiv \left[\frac{P_t Z_t (1-\gamma)(K_t/N_t)^\gamma \left(N_t\right)^{1-\theta}}{W_t(i)} \right]^{\frac{1}{1-\theta}}.$$

Consumer's problem:

The consumer's two stage problem is given by

$$
\begin{aligned}
&V(M_t(i), K_t(i), \bar{S}_t) = \\
&\max_{W_t(i)} E_{(\bar{S}_t)} \left\{ \begin{array}{c} \max_{C_{1t}(i), C_{2t}(i), M_{t+1}(i), K_{t+1}(i)} \ \log([\alpha C_{1t}(i)^{\sigma} + (1-\alpha) C_{2t}(i)^{\sigma}]^{1/\sigma}) \\ +\phi \log(1 - N_t^d(W_t(i))) \\ +\beta E_{S_t} V(M_{t+1}(i)/T_t, K_{t+1}(i), H(S_t), z_t, \tau_t) \end{array} \right\}
\end{aligned}
$$

subject to

$$
\begin{aligned}
&M_t(i) + W_t N_t(i) + R_t K_t(i) + (T_t - 1) M_t \\
&\geq M_{t+1}(i) + P_t \left[K_{t+1}(i) - (1-\delta) K_t(i) + C_{1t}(i) + C_{2t}(i) \right]
\end{aligned}
$$

$$
M_t(i) + (T_t - 1) \geq P_t C_{1t}(i).
$$

The first-order condition for choosing $W_t(i)$ is

$$
E_{\hat{S}_t} \left\{ \frac{-\phi N_t^{d\prime}}{1 - N_t^d} + \lambda_t \left(N_t + W_t(i) N_t^{d\prime} \right) \right\} = 0,
$$

where $N_t^{d\prime}$ is the derivative of labor demand with respect to $W_t(i)$. This implies that

$$
0 = E_{\hat{S}_t} \left\{ \left(\frac{-\phi}{1 - N_t^d} + \lambda_t W_t(i) \right) N_t^{d\prime} + \lambda_t N_t^d \right\}.
$$

Note that in equilibrium,

$$
\begin{aligned}
&\Rightarrow N_t^{d\prime} = -\left(\frac{1}{1-\theta} \right) \left[\frac{P_t Z_t (1-\gamma) (K_t/N_t)^{\gamma} (N_t)^{1-\theta}}{W_t(i)} \right]^{\frac{1}{1-\theta}} W_t(i)^{-1} \\
&= -\left(\frac{1}{1-\theta} \right) \frac{N_t}{W_t},
\end{aligned}
$$

and hence the wage equation becomes

$$\begin{aligned} 0 &= E_{\hat{S}_t}\left\{\left(\frac{-\phi}{1-N_t}+\lambda_t W_t\right)\left[-\left(\frac{1}{1-\theta}\right)\frac{N_t}{W_t}\right]+\lambda_t N_t\right\} \\ &= E_{\hat{S}_t}\left\{\left[\left(\frac{1}{W_t}\frac{\phi}{1-N_t}\right)-\theta\lambda_t\right]N_t\right\}. \end{aligned}$$

In addition to this condition we have the firm's first-order condition for hiring labor, which determines labor demand given the wage. This condition simplifies to the same profit maximization condition that characterizes the misperceptions model:

$$\begin{aligned} &P_t Z_t(1-\gamma)(K_t^d/N_t^d)^\gamma \left(N_t^d\right)^{1-\theta} N_t^d(i)^{\theta-1} = W_t(i) \\ &\Rightarrow P_t Z_t(1-\gamma)(K_t/N_t)^\gamma = W_t. \end{aligned}$$

E. Deriving the Shock from Prices

In our computations, we have chosen to treat the price sequence as the fundamental object from which we derive our shocks to money. Assume that we're starting with some price sequence $\{\bar{p}_t\}_{t=0}^T$; where $\bar{p}_t$ denotes the log of the price index in period t in the data, and $t=0$ is taken to be the starting point.

The initial deviation in the price level is therefore given by $\bar{p}_1-\bar{p}_0$; hence, we can infer our shock directly from

$$s_{1,5} = \frac{\bar{p}_1-\bar{p}_0-D_{p,1:4}s_{1,1:4}}{D_{p,5}}.$$

Now, because of our normalization, the price level in the second period in our model has to be adjusted upward by the negative of the money growth rate this period. Hence, $\hat{p}_2-\hat{\tau}_1$ corresponds to the price level in the model. Therefore,

$$s_{2,5} = \frac{\bar{p}_2-\hat{\tau}_1-\bar{p}_0-D_{p,1:4}s_{2,1:4}}{D_{p,5}}.$$

Hence,

$$s_{t,5} = \frac{\bar{p}_t - \sum_{r=1}^{t-1} \hat{\tau}_r - \bar{p}_0 - D_{p,1:4} s_{t,1:4}}{D_{p,5}}$$

is the formula that we should use in computing the implied innovation to our money supply sequence in the model.

This result indicates that we can compute the implied outcomes of our model, given that we are requiring it to reproduce the normalized price sequence, or

$$\bar{p}_t = \hat{p}_t + \sum_{r=1}^{t-1} \hat{\tau}_r,$$

by iteratively computing the innovation to money $s_{t,5}$, given $\{\bar{p}_t\}$ and $s_{t,1:4}$, then computing the outcomes implied by this innovation in period t, which in turn implies $s_{t+1,1:4}$.

12. Tables

Table 1: Cross-Country Statistics

(Hatted Variables Are Log Deviation from 1929)

	Mean			**Correlation with $\hat{y}$**		**Standard Deviation**		
Year	$\hat{y}$	$\hat{w}-\hat{p}$	π	π	$\hat{w}-\hat{p}$	$\hat{y}$	$\hat{w}-\hat{p}$	π
1930	-0.01	0.05	-0.04	-0.22	0.24	0.04	0.03	0.04
1931	-0.06	0.09	-0.07	-0.28	0.23	0.08	0.05	0.03
1932	-0.10	0.10	-0.05	0.55	-0.04	0.11	0.07	0.05
1933	-0.09	0.10	-0.02	0.36	0.12	0.14	0.07	0.03

Table 2: Output and Prices in 1932

Cumulative Log Changes from 1929

Country	**Output**	**Price**
Australia	-0.07	-0.28
Italy	-0.08	-0.24
U.S.	-0.33	-0.24
Hungary	-0.04	-0.23
Japan	0.05	-0.22
Netherlands	-0.08	-0.20
Germany	-0.28	-0.19
Canada	-0.29	-0.18
Denmark	0.04	-0.17
Finland	-0.04	-0.17
Switzerland	-0.04	-0.17
Sweden	-0.04	-0.15
Norway	0.01	-0.12
Czech.	-0.11	-0.08
U.K.	-0.06	-0.08
Austria	-0.22	-0.02
France	-0.11	-0.02
Mean	-0.08	-0.15

Table 3: Benchmark Parameters						
θ	$\boldsymbol{\beta}$	σ	$\boldsymbol{\delta}$	$\boldsymbol{\alpha}$	$\boldsymbol{\rho_z}$	$\boldsymbol{\rho_\tau}$
.33	.95	.92	.07	.5	.90	.00

Table 4: Impact of a 10 Percent Deflation on Labor ($\hat{n}$) for Different Values of the Nonneutrality Parameter (η)

$\boldsymbol{\eta}$	$\hat{\mathbf{n}}$
0	-14.8%
-0.25	-12.7%
-0.50	-9.8%
-0.75	-5.9%
-1.00	-0.0%

Table 5: Output Decomposition Bounds
Percentage of Output Change Explained by

	Monetary Shock		**Productivity Shock**	
$\boldsymbol{\eta}$	**Lower**	**Upper**	**Lower**	**Upper**
-0.75	6	45	55	94
-0.50	11	46	54	89
-0.25	15	47	53	85
0.00	18	48	52	82

Table 6: Output Decomposition with Alternative Orthogonalization Percentage of Output Change Explained by		
	Money and Non-orthogonal Productivity	**Productivity Orthogonal to Deflation ($\varepsilon_z \perp \boldsymbol{\pi}$)**
1930	21	79
1931	24	76
1932	28	72
1933	30	70

Table 7: Output Change Due to
Country-Specific Component and
Correlation between Output and Price Change

Year	Percentage	Correlation
1930	98	-0.22
1931	62	-0.28
1932	56	0.55
1933	70	0.36

Table 8: Output Decomposition Bounds
Two η Experiment[29]
Percentage of Output Change Explained

Money Shocks		**Productivity Shocks**	
Lower	Upper	Lower	Upper
12	53	47	88

---

[29] The following countries were assigned an η of 0: Austria, Canada, Czechoslovakia, France, Germany, and the United States. The rest were assigned an η of -0.80.

Table 9: Correlation of Industrial Production (IP) and Producer Prices (PPI) and Correlation of IP and Wages Deflated by PPI

(Log-Deviation from 1929)[30]

Year	IP and PPI	IP and W/PPI
1931	-0.34	0.45
1933	-0.25	-0.04

Table 10: Characteristics of the Shocks $\eta = -0.50$

Year	Mean(ε_z)	Std(ε_z)	Mean(ε_τ)	Std(ε_τ)	Corr($\varepsilon_z, \varepsilon_\tau$)
1930	0.01	0.03	-0.04	0.04	-0.23
1931	-0.02	0.03	-0.09	0.03	0.18
1932	-0.03	0.03	-0.08	0.06	0.23
1933	-0.01	0.03	-0.03	0.05	0.56

---

[30] As is typically done in the literature, we included a much broader group of countries because the data availability is greater for these variables. This includes our standard set of countries, except Czechoslovakia, Japan, and Switzerland, and the addition of Hungary. The IP vs. PPI correlation excludes only Japan and Switzerland from our standard set of countries, and also adds Belgium, Estonia, Greece, Hungary, Latvia, Poland, Romania, and Spain.

Table 11: Cross-Country Correlation of TFP with Other Factors in 1932 ($\eta = -0.50$)[31]	
Factors	**Corr**
Trade Share in 1929	0.19
Agricultural Share in 1929	0.42
Change in Real Exchange Rate 1929-32	0.51
Bernanke-James Financial Variable	-0.58
Change in Real Stock Prices 1930-31	0.68
Change in Real Stock Prices 1929-30	0.54

---

[31] All variables, with the exception of the trade and agriculture shares, are in terms of their log-deviation from 1929.

13. Appendix Tables

Tables A1 and A2 show the initial impact of a deflation shock in the sticky wage model and in the misperceptions model with the benchmark value of η.

Table A1: Impulse Response to
1 Percent Negative Money Shock
Sticky Wage Model (in percent)

Period	$\hat{\mathbf{y}}$	$\hat{\mathbf{n}}$	$\hat{\mathbf{w}} - \hat{\mathbf{p}}$	$\hat{\mathbf{p}}$
1	-1.47	-2.19	0.72	-0.72

Table A2: Impulse Response to
1 Percent Negative Money Shock
Misperceptions Model (in percent)
$(\boldsymbol{\eta} = \mathbf{-0.5})$

Period	$\hat{\mathbf{y}}$	$\hat{\mathbf{n}}$	$\hat{\mathbf{w}} - \hat{\mathbf{p}}$	$\hat{\mathbf{p}}$
1	-0.59	-0.87	0.29	-0.89

Table A3 shows the data in Figure 2, and Table A4 shows the data used in Figure 4.

Table A3: Log Deviations from 1929 in Output and Productivity[32]

	Output				**Productivity**			
Country	**1930**	**1931**	**1932**	**1933**	**1930**	**1931**	**1932**	**1933**
Australia	0.01	-0.08	-0.07	-0.01	0.05*	0.01*	0.03*	0.04*
Canada	-0.05	-0.18	-0.29	-0.36	-0.03	-0.13	-0.18	-0.22
France	0.01	-0.06	-0.11	-0.09	0.00	-0.06	-0.10	-0.08
Germany	-0.07	-0.20	-0.28	-0.20	-0.03	-0.07	-0.07	-0.03
Japan	0.01	0.04	0.05	0.09	0.00*	0.06*	0.06*	0.08*
U.K.	0.00	-0.05	-0.06	-0.04	0.01	-0.03	-0.03	-0.04
U.S.	-0.10	-0.19	-0.33	-0.35	-0.06	-0.09	-0.18	-0.20

Table A4: Log Productivity Deviations from 1929[33]

	Model ($\eta = -0.50$)				**Data**			
Country	**1930**	**1931**	**1932**	**1933**	**1930**	**1931**	**1932**	**1933**
Australia	0.07*	0.03*	0.01*	-0.01*	0.05*	0.01*	0.03*	0.04*
Canada	-0.02	-0.09	-0.14	-0.22	-0.03	-0.13	-0.18	-0.22
France	0.01	-0.03	-0.05	-0.04	0.00	-0.06	-0.10	-0.08
Germany	-0.04	-0.10	-0.12	-0.11	-0.03	-0.07	-0.07	-0.03
Japan	0.07*	0.10*	0.01*	0.06*	0.00*	0.06*	0.06*	0.08*
U.K.	0.00	-0.02	-0.02	-0.02	0.01	-0.03	-0.03	-0.04
U.S.	-0.05	-0.08	-0.15	-0.21	-0.06	-0.09	-0.18	-0.20

---

[32] The productivity measure is labor productivity if the variable has an "*" and total factor productivity otherwise.

[33] In order to make as valid a comparison as possible, we compared TFP in the model to TFP in the data, and labor productivity in the model to labor productivity in the data (for those countries for which we only had labor productivity). The productivity measure is labor productivity if the variable has an "*" and total factor productivity otherwise.

Figure 1A: Output and Deflation 1930

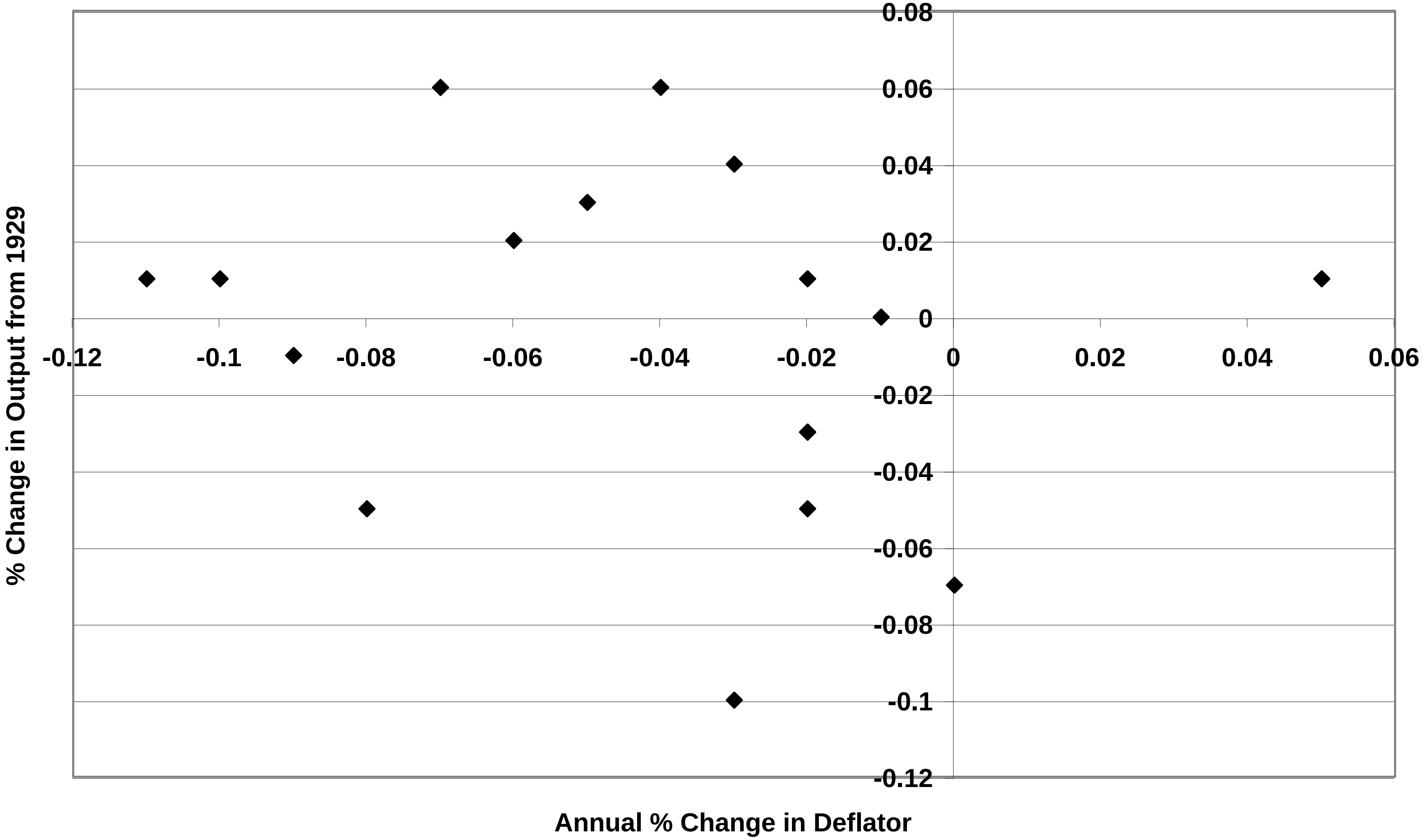

Figure 1B: Output and Deflation 1931

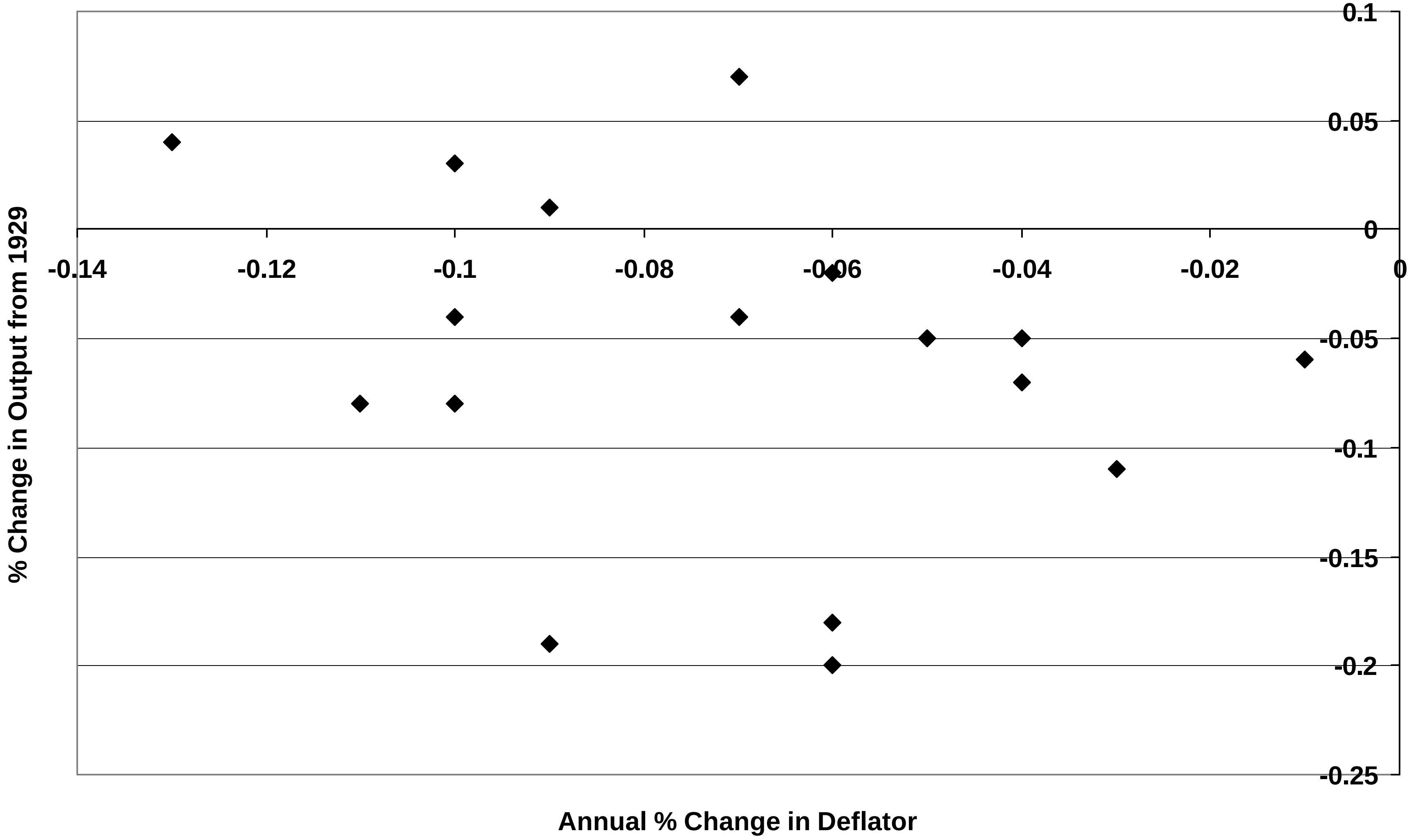

Figure 1C: Output and Deflation 1932

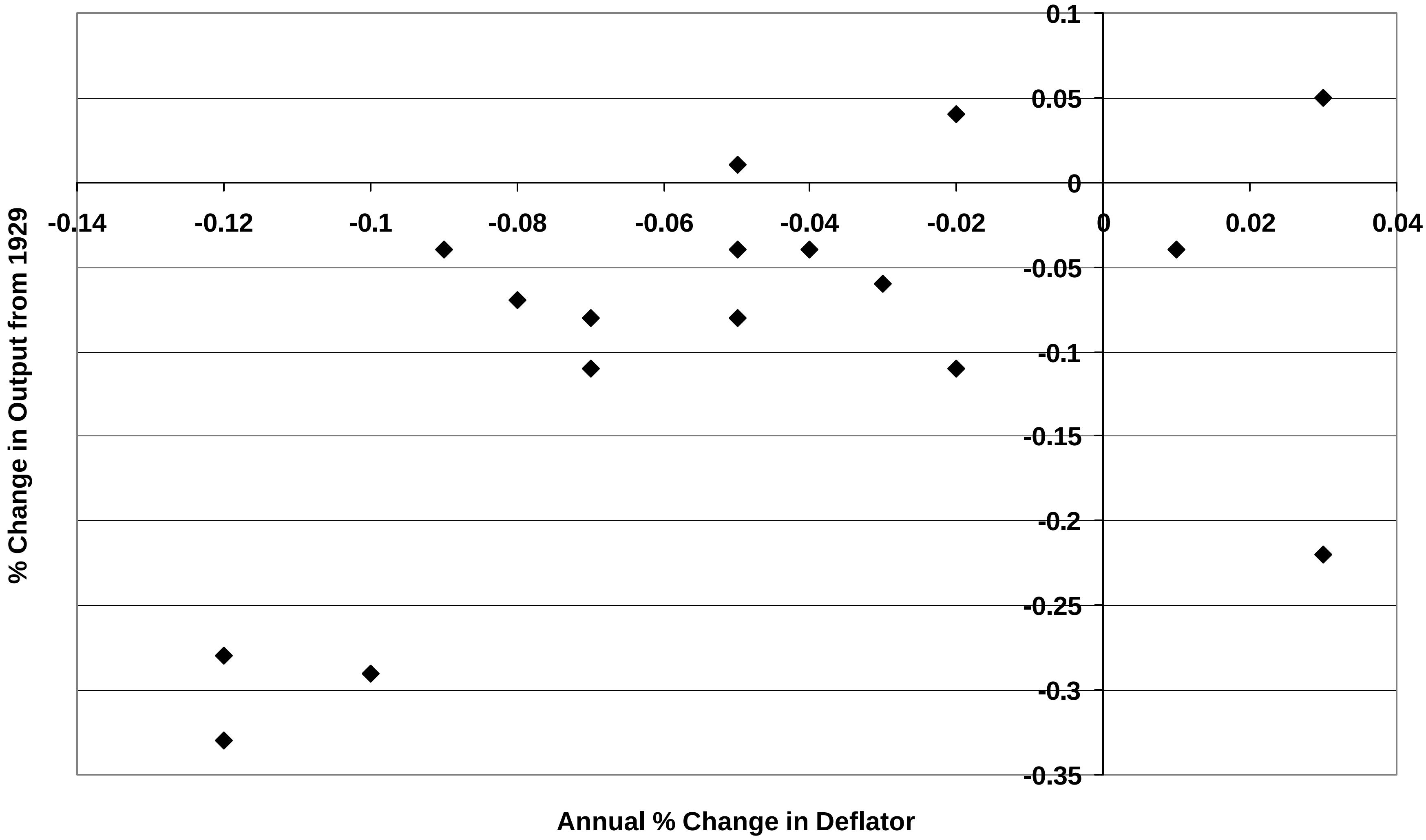

Figure 1D: Output and Deflation 1933

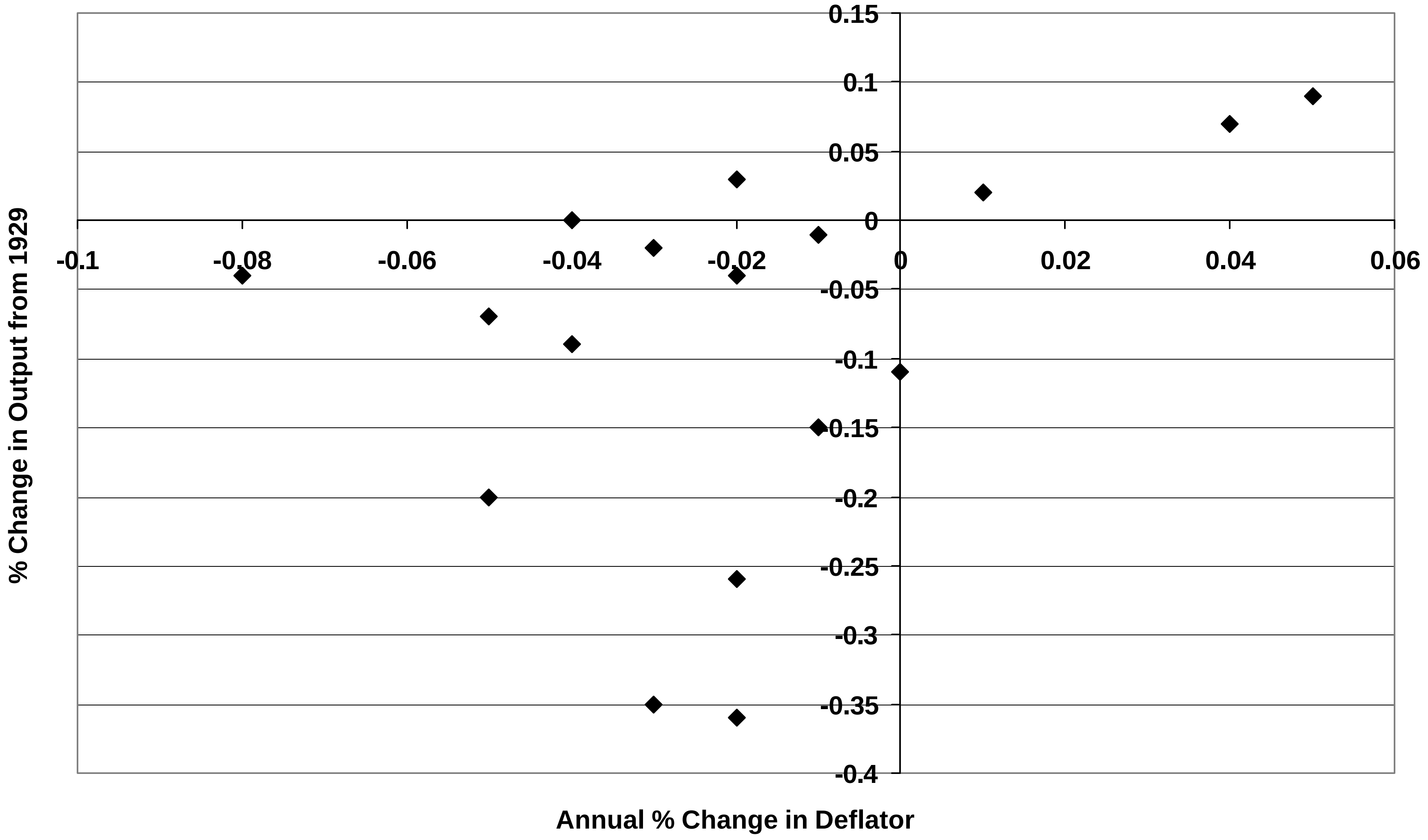

Figure 2: Output and Productivity

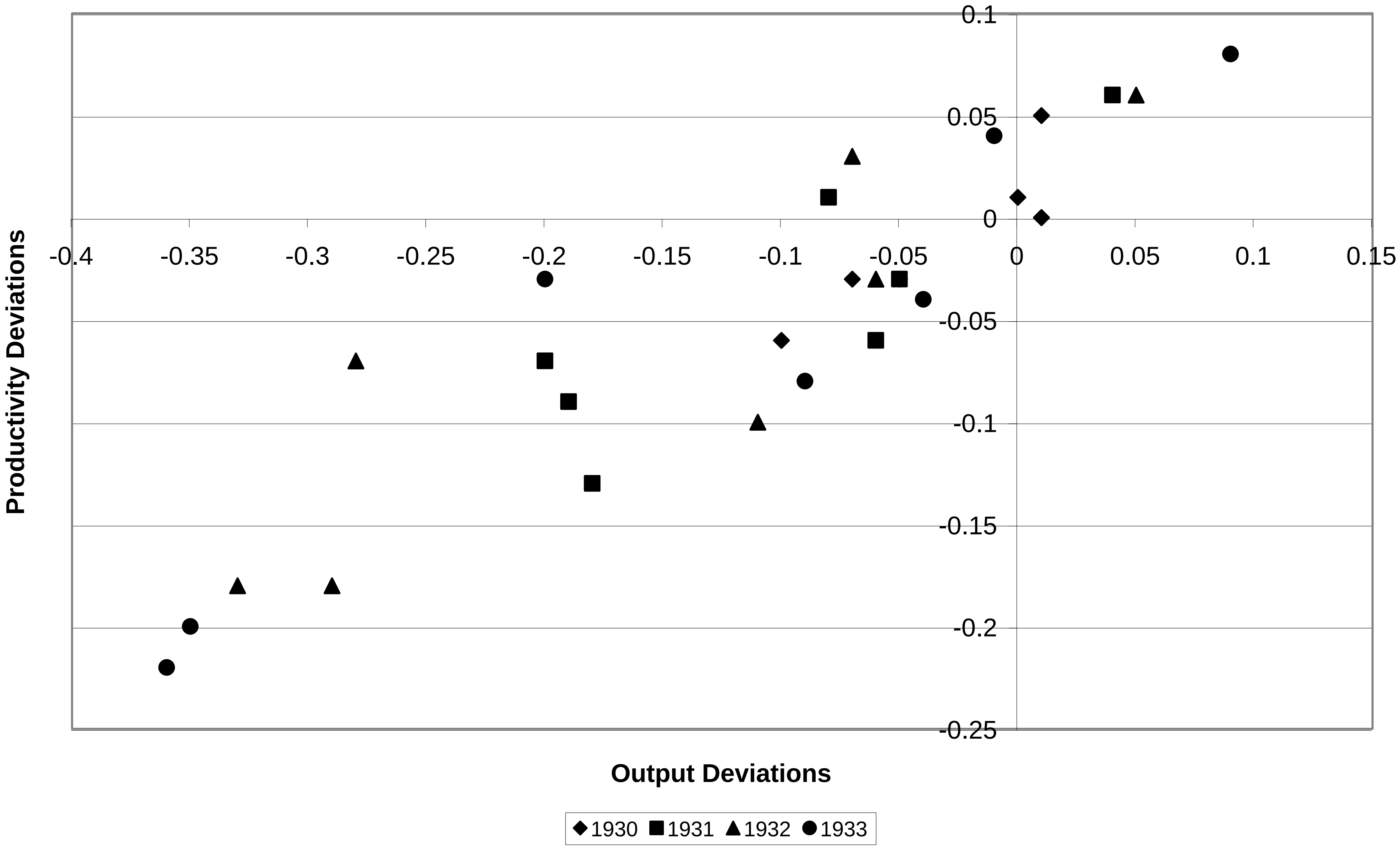

Figure 3A: Output and Real Wages 1930

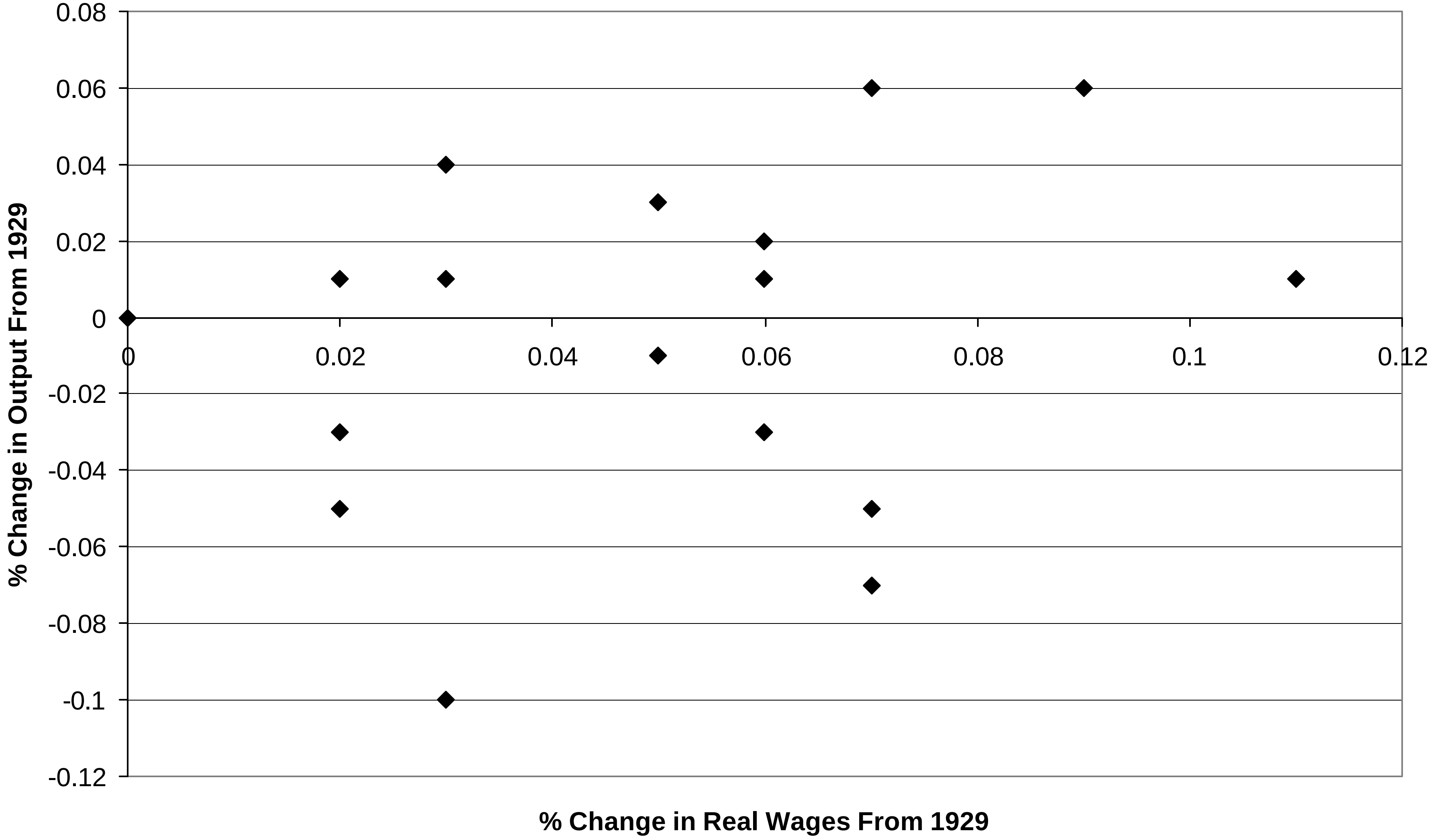

Figure 3B: Output and Real Wages 1931

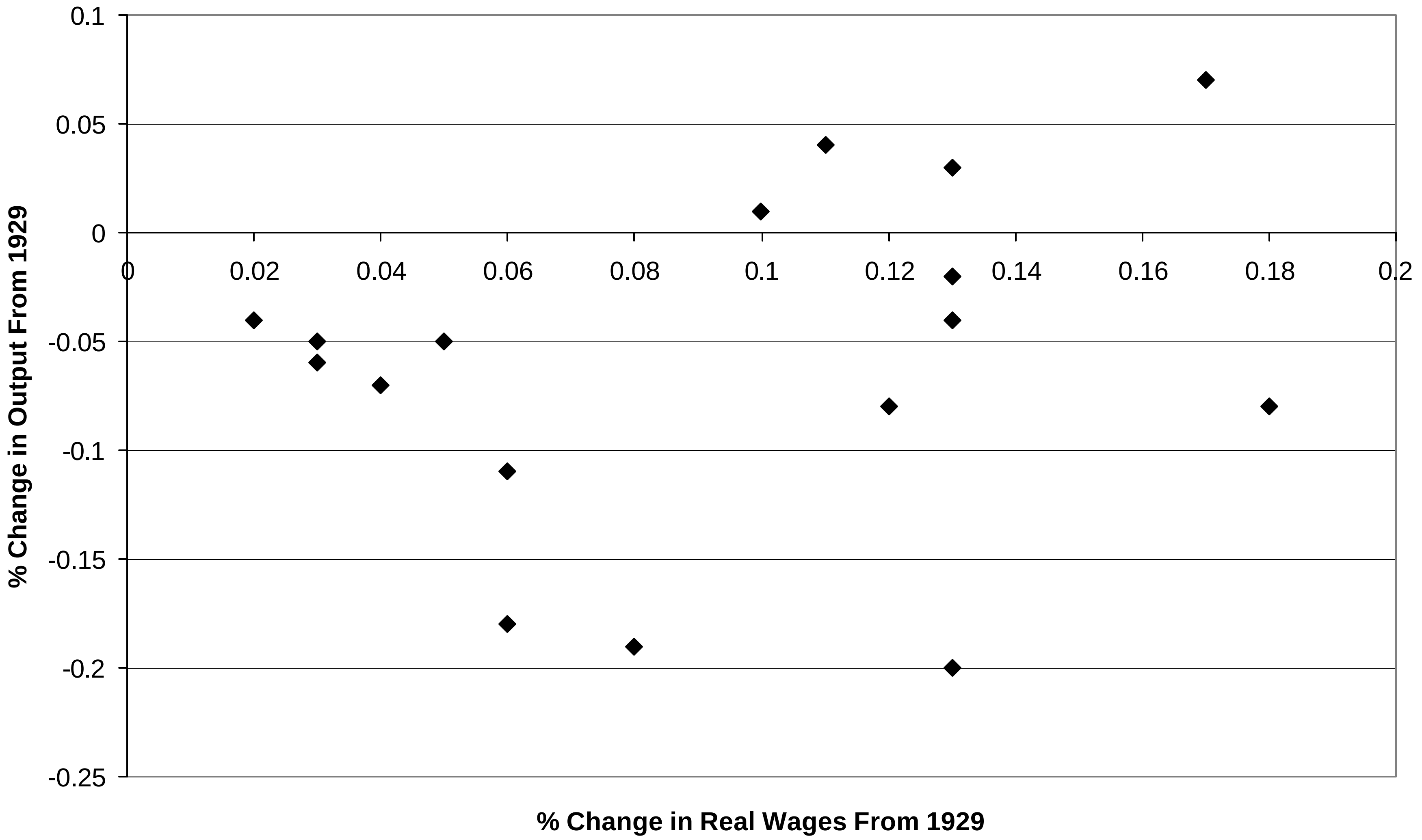

Figure 3C: Output and Real Wages 1932

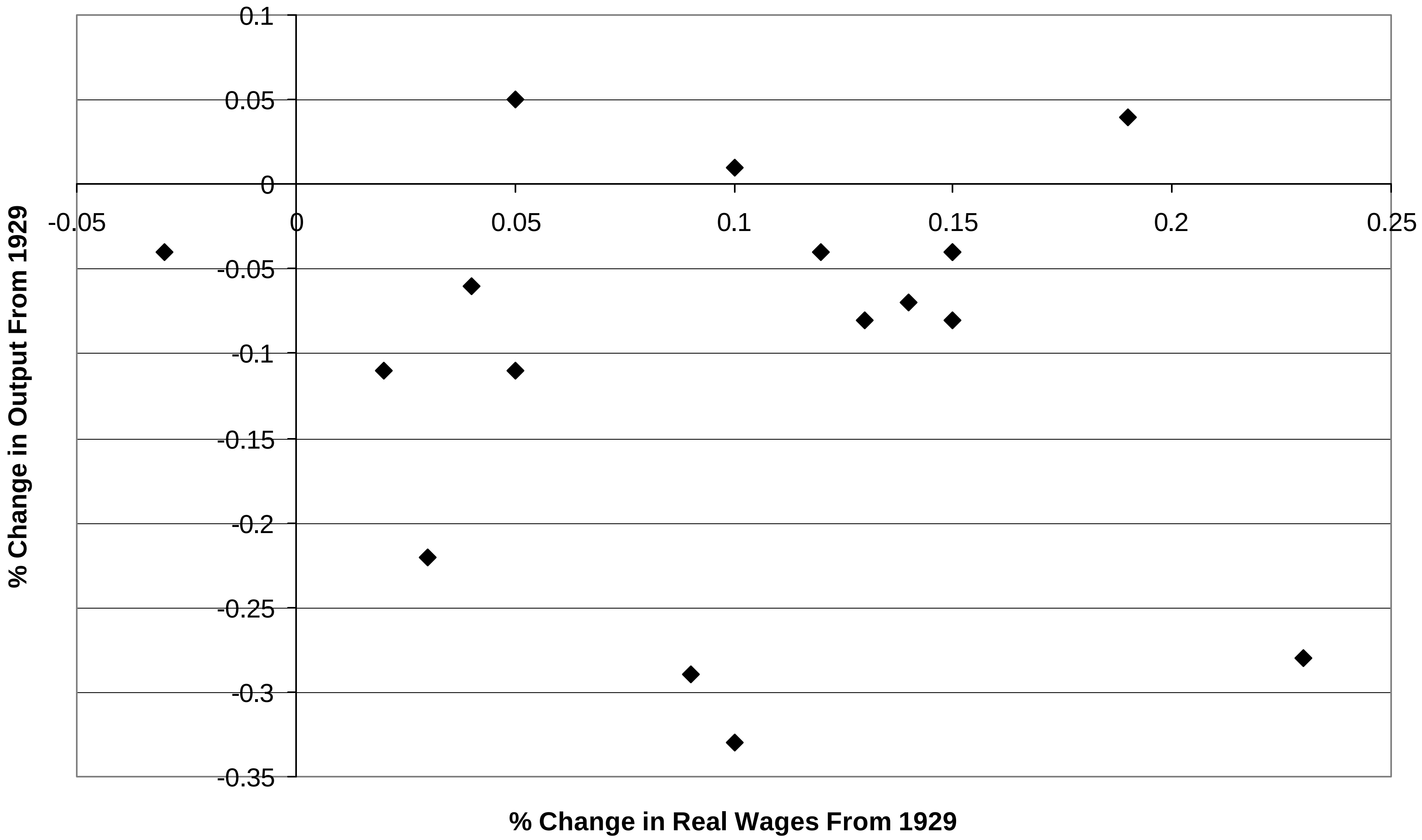

Figure 3D: Output and Real Wages 1933

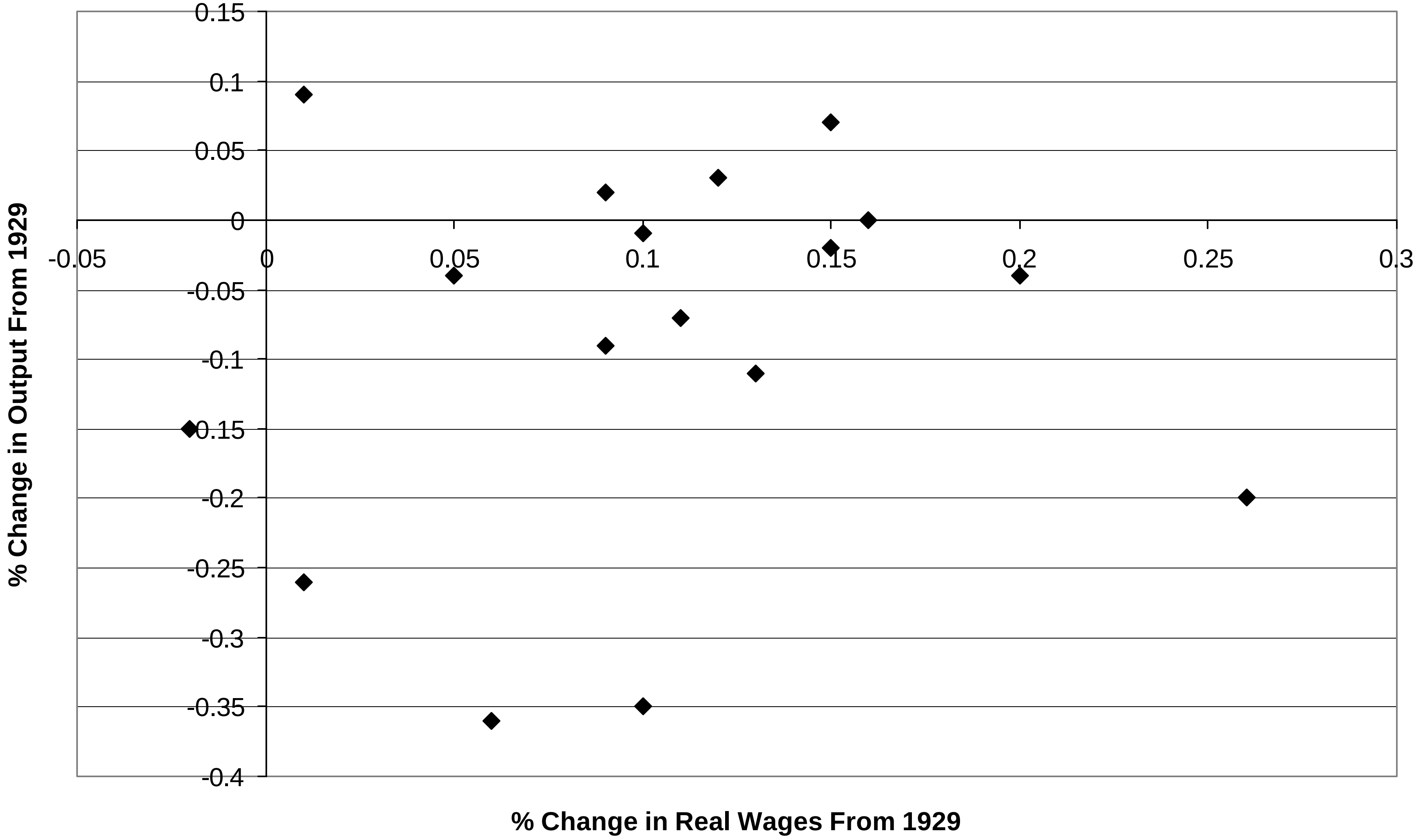

Figure 4: Productivity: Model vs. Data