BUSINESS CYCLE ACCOUNTING

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We propose a simple method to help researchers develop quantitative models of economic fluctuations. The method rests on the insight that many models are equivalent to a prototype growth model with time-varying wedges which resemble productivity, labor and investment taxes, and government consumption. Wedges corresponding to these variables – efficiency, labor, investment, and government consumption wedges – are measured with data and then fed back into the model in order to assess the fraction of various fluctuations accounted for by these wedges. Applying this method to U.S. data for the Great Depression and the 1982 recession reveals that models with frictions which manifest themselves primarily as investment wedges are not promising for the study of business cycles. The efficiency and labor wedges together account for essentially all of the fluctuations, the investment wedge leads to an increase in output rather than a decline, and the government consumption wedge plays an insignificant role.

In building detailed, quantitative models of economic fluctuations, researchers face hard choices about where to introduce frictions into their models in order to allow the models to generate business cycle fluctuations similar to those in the data. Here we propose a simple method to guide these choices, and we demonstrate how to use it.

Our method has two components: an equivalence result and an accounting procedure. The equivalence result is that a large class of models, including models with various types of frictions, are equivalent to a prototype model with various types of time-varying wedges that distort the equilibrium decisions of agents operating in otherwise competitive markets. At face value, these wedges look like time-varying productivity, labor income taxes, investment taxes, and government consumption. We thus label the wedges efficiency wedges, labor wedges, investment wedges, and government consumption wedges.

The accounting procedure also has two components. It begins by measuring the wedges, using data together with the equilibrium conditions of a prototype model. The measured wedge values are then fed back into the prototype model, one at a time and in combinations, in order to decompose the observed movements of output, labor, and investment and assess how much of these movements can be attributed to each wedge, separately and in combinations. By construction, all four wedges account for all of these observed movements. This accounting procedure leads us to label our method business cycle accounting.

To demonstrate how the accounting procedure works, we apply it to two actual U.S. business cycle episodes: the most extreme in U.S. history, the Great Depression (1929–39), and a downturn less severe and more like those seen since World War II, the 1982 recession. For the Great Depression period, we find that, in combination, the efficiency and labor wedges produce declines in output, labor, and investment from 1929 to 1933 only slightly more severe than in the data. These two wedges also account fairly well for the behavior of those variables in the recovery. Over the entire Depression period, the investment wedge actually drives output the wrong way, leading to an increase in output during much of the 1930s. Thus, the investment wedge cannot account for either the long, deep downturn or the subsequent slow recovery. Our analysis of the more typical 1982 U.S. recession produces essentially the same results for the efficiency and labor wedges in combination. Again, the investment wedge drives output the wrong way. In both episodes, the government consumption wedge plays virtually no role.

We extend our analysis to the entire postwar period by developing some summary statistics for 1959–2004. The statistics we focus on are the output fluctuations induced by each wedge alone and the correlations between those fluctuations and those actually in the data. Our findings from these statistics are consistent with those from the analyses of the two separate downturns.

We also investigate whether our results are sensitive to alternative assumptions in the prototype model about features like capital utilization rates, labor supply elasticities, and investment adjustment costs. We find that each of the alternative assumptions we investigate leads to substantial changes in the size of the measured wedges and to the relative contributions of the efficiency and labor wedges but not to the combined contributions of these two wedges. In all of these exercises the investment wedge either drives output the wrong way or plays a quantitatively insignificant role. These exercises demonstrate the robustness of our substantive finding: models with frictions which manifest themselves primarily as investment wedges are not promising.

We establish equivalence results that link the four wedges to detailed models. We show that an economy in which the technology is constant but input-financing frictions vary over time is equivalent to a growth model with efficiency wedges. We show that an economy with sticky wages and monetary shocks, like that of Bordo, Erceg, and Evans (2000), is equivalent to a growth model with labor wedges. In the appendix, we show that an economy with the type of credit market frictions considered by those of Bernanke, Gertler, and Gilchrist (1999) is equivalent to a growth model with investment wedges. Also in the appendix, we show that an open economy model with fluctuating borrowing and lending is equivalent to a prototype (closed-economy) model with government consumption wedges. In the working paper version of this paper (Chari, Kehoe, and McGrattan (2004)), we also show that an economy with the type of credit market frictions considered by Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997) is equivalent to a growth model with investment wedges and that one with unions and antitrust policy shocks, like that of Cole and Ohanian (2004), is equivalent to a growth model with labor wedges.

Our findings here suggest that models like those of Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), and Bernanke, Gertler, and Gilchrist (1999), in which credit market frictions manifest themselves primarily as investment wedges, are not promising avenues for studying the Great Depression or postwar downturns. More promising are sticky wage mechanisms with monetary shocks, such as that of Bordo, Erceg, and Evans (2000), and models with monopoly power, such as that of Cole and Ohanian (2004). In general, this application of our method suggests that successful future work will likely include mechanisms which emphasize the role of efficiency and labor wedges and deemphasize the role of investment wedges. We view this finding as our key substantive contribution.

In terms of method, the equivalence result provides the logical foundation for the way our accounting procedure uses the measured wedges. At a mechanical level, the wedges represent deviations in the prototype model's first-order conditions and in its relationship between inputs and outputs. One interpretation of these deviations, of course, is that they are simply errors, so that their size indicates the goodness-of-fit of the model. Under that interpretation, however, feeding the measured wedges back into the model makes no sense. Our equivalence result leads to a more economically useful interpretation of the deviations by linking them directly to classes of models; that link provides the rationale for feeding the measured wedges back into the model.

Also in terms of method, the accounting procedure goes beyond simply plotting the wedges. Such plots, by themselves, are not useful in evaluating the quantitative importance of competing mechanisms of business cycles because they tell us little about the equilibrium responses to the wedges. Feeding the measured wedges back into the prototype model and measuring the model's resulting equilibrium responses is what allows us to discriminate between competing mechanisms.

Our accounting procedure is intended to be a useful first step in guiding the construction of detailed models with various frictions, to help researchers decide which frictions are quantitatively important to business cycle fluctuations. The procedure is not a way to test particular detailed models. If a detailed model is at hand, then it makes sense to confront that model directly with the data. Nevertheless, our procedure is useful in analyzing models with many frictions. For example, some researchers, such as Bernanke, Gertler, and Gilchrist (1999) and Christiano, Gust, and Roldos (2004), have argued that the data are well accounted for by models which include a host of frictions (such as credit market frictions, sticky wages, and sticky prices). Our analysis suggests that the features of these models which primarily lead to investment wedges can be dropped without substantially affecting the models' ability to account for the data.

Our method is not intended to identify the primitive sources of shocks. Rather, it is intended to help understand the mechanisms through which such shocks lead to economic fluctuations. Many economists think, for example, that monetary shocks drove the U.S. Great Depression, but these economists disagree about the details of the driving mechanism. Our analysis suggests that models in which financial frictions show up primarily as investment wedges are not promising. In our work here, we develop a model, consistent with the views of Bernanke (1983), in which financial frictions show up instead as e ciency wedges. An extension of this model could be fruitful. In this sense, while existing models of financial frictions are not promising, new models in which financial frictions show up as e ciency and labor wedges are.

Other economists, including Cole and Ohanian (1999 and 2004) and Prescott (1999), emphasize nonmonetary factors behind the Great Depression and downplay the importance of money and banking shocks. For such economists, our findings suggest that the model of Cole and Ohanian (2004), in which fluctuations in the power of unions and cartels lead to labor wedges, and other models in which poor government policies lead to e ciency wedges are also promising.

Our work here is related to a vast business cycle literature that we discuss in detail after we describe and apply our new method.

1. Demonstrating the Equivalence Result

Here we show how various detailed models with underlying distortions are equivalent to a prototype growth model with one or more wedges. We choose simple models in order to illustrate how the detailed models map into the prototypes. Since many models map into the same configuration of wedges, identifying one particular configuration does not uniquely identify a model; rather, it identifies a whole class of models consistent with that configuration. In this sense, our method does not uniquely determine the model most promising to analyze business cycle fluctuations. It does, however, guide researchers to focus on the key margins that need to be distorted in order to capture the nature of the fluctuations.

1.1. The Benchmark Prototype Economy

The benchmark prototype economy that we use later in our accounting procedure is a growth model with four stochastic variables: the e ciency wedge A_t, the labor wedge $1 - \tau_{lt}$, the investment wedge $1/(1 + \tau_{xt})$, and the government consumption wedge g_t.

In the model, consumers maximize expected utility over per capita consumption c_t and per capita labor l_t,

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t) N_t,$$

subject to the budget constraint

$$c_t + (1 + \tau_{xt})x_t = (1 - \tau_{lt})w_t l_t + r_t k_t + T_t$$

and the capital accumulation law

$$(1) \qquad (1 + \gamma_n)k_{t+1} = (1 - \delta)k_t + x_t,$$

where k_t denotes the per capita capital stock, x_t per capita investment, w_t the wage rate, r_t the rental rate on capital, β the discount factor, δ the depreciation rate of capital, N_t the population with growth rate equal to $1 + \gamma_n$, and T_t per capita lump-sum transfers.

The firms' production function is $F\left(k_t, (1 + \gamma)^t l_t\right)$, where $1 + \gamma$ is the rate of labor-augmenting technical progress, which is assumed to be a constant. Firms maximize $A_t F\left(k_t, (1 + \gamma)^t l_t\right) - r_t k_t - w_t l_t$.

The equilibrium of this benchmark prototype economy is summarized by the resource constraint,

$$(2) \qquad c_t + x_t + g_t = y_t,$$

where y_t denotes per capita output, together with

$$(3) \qquad y_t = A_t F\left(k_t, (1 + \gamma)^t l_t\right),$$

$$(4) \qquad -\frac{U_{lt}}{U_{ct}} = (1 - \tau_{lt})A_t(1 + \gamma)^t F_{lt}, \text{ and}$$

$$(5) \qquad U_{ct}(1 + \tau_{xt}) = \beta E_t U_{ct+1}[A_{t+1}F_{kt+1} + (1 - \delta)(1 + \tau_{xt+1})],$$

where, here and throughout, notations like U_{ct}, U_{lt}, F_{lt}, and F_{kt} denote the derivatives of the utility function and the production function with respect to their arguments. We assume that g_t fluctuates around a trend of $(1 + \gamma)^t$.

Notice that in this benchmark prototype economy, the efficiency wedge resembles a blueprint technology parameter, and the labor wedge and the investment wedge resemble tax rates on labor income and investment. Other more elaborate models could be considered, models with other kinds of frictions that look like taxes on consumption or on capital income. Consumption taxes induce a wedge between the consumption-leisure marginal rate of substitution and the marginal product of labor in the same way as do labor income taxes. Such taxes, if time-varying, also distort the intertemporal margins in (5). Capital income taxes induce a wedge between the intertemporal marginal rate of substitution and the marginal product of capital which is only slightly different from the distortion induced by a tax on investment.

We emphasize that each of the wedges represents the overall distortion to the relevant equilibrium condition of the model. For example, distortions both to labor supply affecting consumers and to labor demand affecting firms distort the static first-order condition (4). Our labor wedge represents the sum of these distortions. Thus, our method identifies the overall wedge induced by both distortions and does not identify each separately. Likewise, liquidity constraints on consumers distort the consumer's intertemporal Euler equation, while investment financing frictions on firms distort the firm's intertemporal Euler equation. Our method combines the Euler equations for the consumer and the firm and therefore identifies only the overall wedge in the combined Euler equation given by (5). We focus on the overall wedges because what matters in determining business cycle fluctuations is the overall wedges, not each distortion separately.

1.2. The Mapping – From Frictions to Wedges

Now we illustrate the mapping between detailed economies and prototype economies for two types of wedges. We show that input-financing frictions in a detailed economy map into efficiency wedges in our prototype economy. Sticky wages in a monetary economy map into our prototype (real) economy with labor wedges. In an appendix, we show as well that investment-financing frictions map into investment wedges and that fluctuations in net exports in an open economy map into government consumption wedges in our prototype (closed) economy. In general, our approach is to show that the frictions associated with specific economic environments manifest themselves as distortions in first-order conditions and resource constraints in a growth model. We refer to these distortions as wedges.

a. Efficiency Wedges

In many economies, underlying frictions either within or across firms cause factor inputs to be used inefficiently. These frictions in an underlying economy often show up as aggregate productivity shocks in a prototype economy similar to our benchmark economy. Schmitz (2005) presents an interesting example of within-firm frictions resulting from work rules that lower measured productivity at the firm level. Lagos (2004) also studies how labor market policies lead to misallocations of labor across firms and, thus, to lower aggregate productivity. Finally, Chu (2001) and Restuccia and Rogerson (2003) show how government policies at the levels of plants and establishments lead to lower aggregate productivity.

Here we develop a detailed economy with input-financing frictions and use it to make two points. This economy illustrates the general idea that frictions which lead to inefficient factor utilization map into efficiency wedges in a prototype economy. Beyond that, however, the economy also demonstrates that financial frictions can show up as efficiency wedges rather than as investment wedges. In our detailed economy, financing frictions lead some firms to pay higher interest rates for working capital than other firms. Thus, these frictions lead to an inefficient allocation of inputs across firms.

¤ A Detailed Economy With Input-Financing Frictions

Consider a simple detailed economy with financing frictions which distort the allocation of intermediate inputs across two types of firms. Both types of firms must borrow to pay for an intermediate input in advance of production. One type of firm is more financially constrained, in the sense that it pays a higher interest rate on borrowing than does the other type. We think of these frictions as capturing the idea that some firms, such as small firms, often have di culty borrowing. One motivation for the higher interest rate faced by the financially constrained firms is that moral hazard problems are more severe for small firms.

Specifically, consider the following economy. Aggregate gross output q_t is a combination of the gross output q_{it} from the economy's two sectors, indexed $i = 1, 2$, where 1 indicates the sector of firms that are more financially constrained and 2 the sector of firms that are less financially constrained. The sectors' gross output is combined according to

(6) $$q_t = q_{1t}^{\varphi} q_{2t}^{1-\varphi},$$

where $0 < \varphi < 1$. The representative producer of the gross output q_t chooses q_{1t} and q_{2t} to solve this problem:

$$\max\ q_t - p_{1t}q_{1t} - p_{2t}q_{2t}$$

subject to (6), where p_{it} is the price of the output of sector i.

The resource constraint for gross output in this economy is

(7) $$c_t + k_{t+1} + m_{1t} + m_{2t} = q_t + (1 - \delta)k_t,$$

where c_t is consumption, k_t is the capital stock, and m_{1t} and m_{2t} are intermediate goods used in sectors 1 and 2, respectively. Final output, given by $y_t = q_t - m_{1t} - m_{2t}$, is gross output less the intermediate goods used.

The gross output of each sector i, q_{it}, is made from intermediate goods m_{it} and a composite value-added good z_{it} according to

(8) $$q_{it} = m_{it}^{\theta} z_{it}^{1-\theta},$$

where $0 < \theta < 1$. The composite value-added good is produced from capital k_t and labor l_t according to

(9) $$z_{1t} + z_{2t} = z_t = F(k_t, l_t).$$

The producer of gross output of sector i chooses the composite good z_{it} and the intermediate good m_{it} to solve this problem:

$$\max\ p_{it}q_{it} - v_t z_{it} - R_{it}m_{it}$$

subject to (8). Here v_t is the price of the composite good and R_{it} is the gross within-period interest rate paid on borrowing by firms in sector i. If firms in sector 1 are more financially constrained than those in sector 2, then $R_{1t} > R_{2t}$. Let $R_{it} = R_t(1 + \tau_{it})$, where R_t is the rate consumers earn within period t and τ_{it} measures the within-period spread, induced by financing constraints, between the rate paid to consumers who save and the rate paid by firms in sector i. Since consumers do not discount utility within the period, $R_t = 1$.

In this economy, the representative producer of the composite good z_t chooses k_t and l_t to solve this problem:

$$\max \; v_t z_t - w_t l_t - r_t k_t$$

subject to (9), where w_t is the wage rate and r_t is the rental rate on capital.

Consumers solve this problem:

$$(10) \quad \max \sum_{t=0}^{\infty} \beta^t U(c_t, l_t)$$

subject to

$$c_t + k_{t+1} = r_t k_t + w_t l_t + (1 - \delta)k_t + T_t,$$

where $l_t = l_{1t} + l_{2t}$ is the economy's total labor supply and $T_t = R_t \sum_i \tau_{it} m_{it}$ is lump-sum transfers. Here we assume that the financing frictions act like distorting taxes, and the proceeds are rebated to consumers. If, instead, we assumed that the financing frictions represent, say, lost gross output, then we would adjust the economy's resource constraint (7) appropriately.

¤ The Associated Prototype Economy With Efficiency Wedges

Now consider a version of the benchmark prototype economy that will have the same aggregate allocations as the input-financing frictions economy just detailed. This prototype economy is identical to our benchmark prototype except that the new prototype economy has an investment wedge that resembles a tax on capital income rather than a tax on investment. Here the government consumption wedge is set equal to zero.

Now the consumer's budget constraint is

$$(11) \quad c_t + k_{t+1} = (1 - \tau_{kt}) r_t k_t + (1 - \tau_{lt}) w_t l_t + (1 - \delta)k_t + T_t,$$

and the efficiency wedge is

$$(12) \quad A_t = \kappa (a_{1t}^{1-\varphi} a_{2t}^{\varphi})^{\frac{\theta}{1-\theta}} [1 - \theta(a_{1t} + a_{2t})],$$

where $a_{1t} = \varphi/(1+\tau_{1t})$, $a_{2t} = (1-\varphi)/(1+\tau_{2t})$, $\kappa = [\varphi^{\varphi}(1-\varphi)^{1-\varphi}\theta^{\theta}]^{\frac{1}{1-\theta}}$, and τ_{1t} and τ_{2t} are the interest rate spreads in the detailed economy.

Comparing the first-order conditions in the detailed economy with input-financing frictions to those of the associated prototype economy with e ciency wedges leads immediately to this proposition:

PROPOSITION 1: Consider the prototype economy with resource constraint (2) and consumer budget constraint (11) with exogenous processes for the e ciency wedge A_t given in (12), the labor wedge given by

$$(13) \qquad \frac{1}{1-\tau_{lt}} = \frac{1}{1-\theta}\left[1-\theta\left(\frac{\varphi}{1+\tau_{1t}^*}+\frac{1-\varphi}{1+\tau_{2t}^*}\right)\right],$$

and the investment wedge given by $\tau_{kt} = \tau_{lt}$, where τ_{1t}^* and τ_{2t}^* are the interest rate spreads from the detailed economy with input-financing frictions. Then the equilibrium allocations for aggregate variables in the detailed economy are equilibrium allocations in this prototype economy.

Consider the following special case of Proposition 1 in which only the e ciency wedge fluctuates. Specifically, suppose that in the detailed economy the interest rate spreads τ_{1t} and τ_{2t} fluctuate over time, but in such a way that the weighted average of these spreads,

$$(14) \qquad a_{1t} + a_{2t} = \frac{\varphi}{1+\tau_{1t}} + \frac{1-\varphi}{1+\tau_{2t}},$$

is constant while $a_{1t}^{1-\varphi}a_{2t}^{\varphi}$ fluctuates. Then from (13) we see that the labor and investment wedges are constant, and from (12) we see that the e ciency wedge fluctuates. In this case, on average, financing frictions are unchanged, but relative distortions fluctuate. An outside observer who attempted to fit the data generated by the detailed economy with input-financing frictions to the prototype economy would identify the fluctuations in relative distortions with fluctuations in technology and would see no fluctuations in either the labor wedge $1-\tau_{lt}$ or the investment wedge τ_{kt}. In particular, periods in which the relative distortions increase would be misinterpreted as periods of technological regress.

b. Labor Wedges

Now we show that a monetary economy with sticky wages is equivalent to a (real) prototype economy with labor wedges. In the detailed economy the shocks are to monetary policy, while in the prototype economy the shocks are to the labor wedge.

¤ A Detailed Economy With Sticky Wages

Consider a monetary economy populated by a large number of identical, infinitely lived consumers. In each period t, the economy experiences one of finitely many events s_t, which index the shocks. We denote by $s^t = (s_0, ..., s_t)$ the history of events up through and including period t. The probability, as of period 0, of any particular history s^t is $\pi(s^t)$. The initial realization s_0 is given. The economy consists of a competitive final goods producer and a continuum of monopolistically competitive unions that set their nominal wages in advance of the realization of shocks to the economy. Each union represents all consumers who supply a specific type of labor.

In each period t, the commodities in this economy are a consumption-capital good, money, and a continuum of differentiated types of labor, indexed by $j \in [0,1]$. The technology for producing final goods from capital and a labor aggregate at history, or state, s^t has constant returns to scale and is given by $y(s^t) = F\left(k(s^{t-1}), l(s^t)\right)$, where $y(s^t)$ is output of the final good, $k(s^{t-1})$ is capital, and

$$(15) \qquad l(s^t) = \left[\int l(j, s^t)^v \, dj\right]^{\frac{1}{v}}$$

is an aggregate of the differentiated types of labor $l(j, s^t)$.

The final goods producer in this economy behaves competitively. This producer has some initial capital stock $k(s^{-1})$ and accumulates capital according to $k(s^t) = (1 - \delta)k(s^{t-1}) + x(s^t)$, where $x(s^t)$ is investment. The present discounted value of profits for this producer is

$$(16) \qquad \sum_{t=0}^{\infty} \sum_{s^t} Q(s^t) \left[P(s^t)y(s^t) - P(s^t)x(s^t) - W(s^{t-1})l(s^t)\right],$$

where $Q(s^t)$ is the price of a dollar at s^t in an abstract unit of account, $P(s^t)$ is the dollar price of final goods at s^t, and $W(s^{t-1})$ is the aggregate nominal wage at s^t which depends on only s^{t-1} because of wage stickiness.

The producer's problem can be stated in two parts. First, the producer chooses sequences for capital $k(s^{t-1})$, investment $x(s^t)$, and aggregate labor $l(s^t)$ in order to maximize (16) given the production function and the capital accumulation law. The first-order conditions can be summarized by

$$(17) \qquad P(s^t)F_l(s^t) = W(s^{t-1}) \text{ and}$$

$$(18) \qquad Q(s^t)P(s^t) = \sum_{s_{t+1}} Q(s^{t+1})P(s^{t+1})[F_k(s^{t+1}) + 1 - \delta].$$

Second, for any given amount of aggregate labor $l(s^t)$, the producer's demand for each type of differentiated labor is given by the solution to

$$(19) \qquad \min_{\{l(j,s^t)\}, j\in[0,1]} \int W(j, s^{t-1})l(j, s^t) \, dj$$

subject to (15); here $W(j, s^{t-1})$ is the nominal wage for di erentiated labor of type j. Nominal wages are set by unions before the realization of the event in period t; thus, wages depend on, at most, s^{t-1}. The demand for labor of type j by the final goods producer is

$$l^d(j, s^t) = \left[\frac{W(s^{t-1})}{W(j, s^{t-1})}\right]^{\frac{1}{1-v}} l(s^t), \tag{20}$$

where $W(s^{t-1}) \equiv \left[\int W(j, s^{t-1})^{\frac{v}{v-1}} dj\right]^{\frac{v-1}{v}}$ is the aggregate nominal wage. The minimized value in (19) is, thus, $W(s^{t-1})l(s^t)$.

Consumers can be thought of as being organized into a continuum of unions indexed by j. Each union consists of all the consumers in the economy with labor of type j. Each union realizes that it faces a downward-sloping demand for its type of labor, given by (20). In each period, the new wages are set before the realization of the economy's current shocks.

The preferences of a representative consumer in the jth union is

$$\sum_{t=0}^{\infty}\sum_{s^t} \beta^t \pi(s^t) \left[U(c(j, s^t), l(j, s^t)) + V(M(j, s^t)/P(s^t))\right], \tag{21}$$

where $c(j, s^t), l(j, s^t), M(j, s^t)$ are the consumption, labor supply, and money holdings of this consumer, and $P(s^t)$ is the economy's overall price level. Note that the utility function is separable in real balances. This economy has complete markets for state-contingent nominal claims. The asset structure is represented by a set of complete, contingent, one-period nominal bonds. Let $B(j, s^{t+1})$ denote the consumers' holdings of such a bond purchased in period t at history s^t, with payo s contingent on some particular event s_{t+1} in $t+1$, where $s^{t+1} = (s^t, s_{t+1})$. One unit of this bond pays one dollar in period $t+1$ if the particular event s_{t+1} occurs and 0 otherwise. Let $Q(s^{t+1}|s^t)$ denote the dollar price of this bond in period t at history s^t, where $Q(s^{t+1}|s^t) = Q(s^{t+1})/Q(s^t)$.

The problem of the jth union is to maximize (21) subject to the budget constraint

$$\begin{aligned} &P(s^t)c(j, s^t) + M(j, s^t) + \sum_{s_{t+1}} Q(s^{t+1}|s^t)B(j, s^{t+1}) \\ &\qquad \le W(j, s^{t-1})l(j, s^t) + M(j, s^{t-1}) + B(j, s^t) + P(s^t)T(s^t) + D(s^t), \end{aligned}$$

the constraint $l(j, s^t) = l^d(j, s^t)$, and the borrowing constraint $B(s^{t+1}) \ge -P(s^t)\bar{b}$, where $l^d(j, s^t)$ is given by (20). Here $T(s^t)$ is transfers and the positive constant $\bar{b}$ constrains the amount of real borrowing by the union. Also, $D(s^t) = P(s^t)y(s^t) - P(s^t)x(s^t) - W(s^{t-1})l(s^t)$ are the dividends paid by the firms. The initial conditions $M(j, s^{-1})$ and $B(j, s^0)$ are given and assumed to be the same for all j. Notice that in this problem, the union chooses the wage and agrees to supply whatever labor is demanded at that wage.

The first-order conditions for this problem can be summarized by

$$(22)\qquad \frac{V_m(j,s^t)}{P(s^t)} - \frac{U_c(j,s^t)}{P(s^t)} + \beta\sum_{s_{t+1}}\pi(s^{t+1}|s^t)\frac{U_c(j,s^{t+1})}{P(s^{t+1})} = 0,$$

$$(23)\qquad Q(s^t|s^{t-1}) = \beta\pi(s^t|s^{t-1})\frac{U_c(j,s^t)}{U_c(j,s^{t-1})}\frac{P(s^{t-1})}{P(s^t)}, \text{ and}$$

$$(24)\qquad W(j,s^{t-1}) = -\frac{\sum_{s^t} Q(s^t)P(s^t)U_l(j,s^t)/U_c(j,s^t)l^d(j,s^t)}{v\sum_{s^t} Q(s^t)l^d(j,s^t)}.$$

Here $\pi(s^{t+1}|s^t) = \pi(s^{t+1})/\pi(s^t)$ is the conditional probability of s^{t+1} given s^t. Notice that in a steady state, (24) reduces to $W/P = (1/v)(-U_l/U_c)$, so that real wages are set as a markup over the marginal rate of substitution between labor and consumption. Given the symmetry among the unions, all of them choose the same consumption, labor, money balances, bond holdings, and wages, which are denoted simply by $c(s^t)$, $l(s^t)$, $M(s^t)$, $B(s^{t+1})$, and $W(s^t)$.

Consider next the specification of the money supply process and the market-clearing conditions. The nominal money supply process is given by $M(s^t) = \mu(s^t)M(s^{t-1})$, where $\mu(s^t)$ is a stochastic process. New money balances are distributed to consumers in a lump-sum fashion by having nominal transfers satisfy $P(s^t)T(s^t) = M(s^t) - M(s^{t-1})$. The resource constraint for this economy is $c(s^t) + k(s^t) = y(s^t) + (1-\delta)k(s^{t-1})$. Bond market–clearing requires that $B(s^{t+1}) = 0$.

¤ The Associated Prototype Economy With Labor Wedges

Consider now a real prototype economy with labor wedges and the production function for final goods given above in the detailed economy with sticky wages. The representative firm maximizes (16) subject to the capital accumulation law given above. The first-order conditions can be summarized by (17) and (18). The representative consumer maximizes

$$\sum_{t=0}^{\infty}\sum_{s^t}\beta^t\pi(s^t)U(c(s^t),l(s^t))$$

subject to the budget constraint

$$c(s^t) + \sum_{s_{t+1}} q(s^{t+1}|s^t)b(s^{t+1}) \le (1-\tau_l(s^t))w(s^t)l(s^t) + b(s^t) + v(s^t) + d(s^t)$$

with $w(s^t)$ replacing $W(s^{t-1})/P(s^t)$ and $q(s^{t+1}/s^t)$ replacing $Q(s^{t+1})P(^{st+1})/Q(s^t)P(s^t)$ and a bound on real bond holdings, where the lowercase letters q, b, w, v, and d denote the real values of bond prices, debt, wages, lump-sum transfers, and dividends. Here the first-order condition for bonds is identical to that in (23) once symmetry has been imposed with $q(s^t/s^{t-1})$ replacing $Q(s^t/s^{t-1})P(s^t)/P(s^{t-1})$. The first-order condition for labor is given by

$$-\frac{U_l(s^t)}{U_c(s^t)} = (1-\tau_l(s^t))w(s^t).$$

Consider an equilibrium of the sticky wage economy for some given stochastic process $M^*(s^t)$ on money supply. Denote all of the allocations and prices in this equilibrium with asterisks. Then this proposition can be easily established:

PROPOSITION 2: Consider the prototype economy just described with labor wedges given by

$$(25) \qquad 1 - \tau_l(s^t) = -\frac{U_l^*(s^t)}{U_c^*(s^t)} \frac{1}{F_l^*(s^t)},$$

where $U_l^*(s^t), U_c^*(s^t)$, and $F_l^*(s^t)$ are evaluated at the equilibrium of the sticky wage economy and where real transfers are equal to the real value of transfers in the sticky wage economy adjusted for the interest cost of holding money. Then the equilibrium allocations and prices in the sticky wage economy are the same as those in the prototype economy.

The proof of this proposition is immediate from comparing the first-order conditions, the budget constraints, and the resource constraints for the prototype economy with labor wedges to those of the detailed economy with sticky wages. The key idea is that distortions in the sticky-wage economy between the marginal product of labor implicit in (24) and the marginal rate of substitution between leisure and consumption are perfectly captured by the labor wedges (25) in the prototype economy.

2. Applying the Accounting Procedure

Having established our equivalence result, we now describe our accounting procedure and demonstrate how to apply it to two U.S. business cycle episodes: the Great Depression and the postwar recession of 1982. We then extend our analysis to the entire postwar period. (In a technical appendix, Chari, Kehoe, and McGrattan (2006), we describe in detail our data sources, parameter choices, computational methods, and estimation procedures.)

2.1. The Procedure

Our accounting procedure works as follows. We choose our benchmark prototype model's parameters of preferences and technology in standard ways, as in the quantitative business cycle literature, and then use the equilibrium conditions of our prototype economy to estimate the parameters of a stochastic process for the wedges. Given these parameters, we compute decision rules for output, labor, and investment. We use these decision rules together with the data both to uncover a stochastic process for the wedges and to derive the realized values of the wedges in the data.

We then ask, How much of the output fluctuations can be accounted for by each of the wedges, separately and in various combinations? To answer this question, we first simulate our prototype model using the realized sequence of wedges in the data. We then measure the contribution of these wedges to fluctuations in output, labor, and investment by comparing the realizations of these variables from the model to their analogs in data. Our approach is an accounting procedure since, by construction, all the wedges together account for all of the movements in the variables.

a. Wedge Measurement

Our process for measuring the wedges has two steps. We use both the data and the models first to estimate the stochastic process for the wedges and then to measure the realized wedges.

¤ Estimating the Stochastic Process for the Wedges

To estimate the stochastic process for the wedges, we use functional forms and parameter values familiar from the business cycle literature. We assume that the production function has the form $F(k,l) = k^{\alpha}l^{1-\alpha}$ and the utility function the form $U(c,l) = \log c + \psi \log(1-l)$. We choose the capital share $\alpha = .35$ and the time allocation parameter $\psi = 2.24$. We choose the depreciation rate δ, the discount factor β, and growth rates γ and γ_n so that, on an annualized basis, depreciation is 4.64%, the rate of time preference is 3%, the population growth rate is 1.5%, and the growth of technology is 1.6%. (To keep the notion simple, throughout Sections 2 and 3 we abstract from population and technological growth. See our technical appendix for details.)

Equations (2)–(5) summarize the equilibrium of the benchmark prototype economy. We substitute for consumption c_t in (4) and (5) using the resource constraint (2), then log-linearize (3)–(5) to get three linear equations. We specify a vector autoregressive AR(1) process for the four wedges $s_t = (\log A_t, \tau_{lt}, \tau_{xt}, \log g_t)$ of the form

(26) $$s_{t+1} = P_0 + P s_t + \varepsilon_{t+1},$$

where the shock ε_t is i.i.d. over time and is distributed normally with mean zero and covariance matrix V. To ensure that our estimate of V is positive semidefinite, we estimate the lower triangular matrix Q, where $V = QQ'$. The matrix Q has no structural interpretation. Below we elaborate on the contrast between our decomposition and more traditional decompositions which impose structural interpretations on Q.

We then have seven equations, three from the equilibrium and four from (26). We use a standard maximum likelihood procedure and data on output, labor, investment, and the sum of government con-

construct labor and investment due to the various components similarly.

We also construct joint components. Define the e ciency plus labor component by letting s_{5t} = $(\log A_t, \tau_{lt}, \tau_{x0}, \log g_0)$, and define the other joint components similarly.

2.2. Accounting Details and Findings

Now we describe the details of implementing our procedure and the results of applying it to two historical U.S. business cycle episodes. In the Great Depression, the e ciency and the labor wedge play a central role. In the 1982 recession, the e ciency wedge plays a central role for output and investment while the labor wedge plays a central role for labor. The government consumption wedge plays no role in either period. The most striking result overall is that the investment wedge does not help in accounting either for the downturn or for the recovery during either the Great Depression or the 1982 period.

a. Details of the Procedure

In order to implement our accounting procedure, we must first adjust the data to make it consistent with the theory. In particular, we adjust the U.S. data on output and its components to remove sales taxes and to add the service flow for consumer durables. For the pre–World War II period, we remove military compensation as well. We estimate separate sets of parameters for the stochastic process for wedges (26) for each of our two historical episodes. The other parameters are the same in the two episodes. See Chari, Kehoe, and McGrattan (2006) for our rationale for this choice. The stochastic process parameters for the Great Depression analysis are estimated using annual data for 1901–40; those for analysis after World War II, using quarterly data for 1959:1–2004:3. In the Great Depression analysis, we impose the additional restriction that the covariance between the shocks to the government consumption wedge and those to the other wedges is zero. This restriction avoids having the large movements in government consumption associated with World War I dominate the estimation of the stochastic process.

Table I displays the resulting estimated values for the parameters of the coe cient matrices, P and Q, and the associated confidence bands for our two data periods. The stochastic process (26) with these values will be used by agents in our economy to form their expectations about future wedges. In the data, we remove a trend of 1.6% from output, investment, and the government consumption wedge. Both output and labor are normalized to equal 100 in the base periods: 1929 for the Great Depression and 1979:1 for the 1982 recession. In both of these historical episodes, investment (detrended) is divided by the base period level of output. Since the government consumption component accounts for virtually none of the fluctuations in output, labor, and investment, we discuss the government consumption wedge and its components in detail elsewhere (in Chari, Kehoe, and McGrattan (2006)). Here we focus primarily on the fluctuations due to the efficiency, labor, and investment wedges.

b. Findings: The Great Depression . . .

Our findings for the period 1929–39, which includes the Great Depression, are displayed in Figures 1–4. We find that the efficiency and labor wedges account for essentially all of the movements of output, labor, and investment in the Depression period and that the investment wedge actually drives output the wrong way.

In Figure 1, we display actual U.S. output along with the three measured wedges for that period: the efficiency wedge A, the labor wedge $(1 - \tau_l)$, and the investment wedge $1/(1 + \tau_x)$. We see that the underlying distortions revealed by the three wedges have different patterns. The distortions that manifest themselves as efficiency and labor wedges become substantially worse between 1929 and 1933. By 1939, the efficiency wedge has returned to the 1929 trend level, but the labor wedge has not. Over the period, the investment wedge fluctuates, but investment decisions are generally less distorted, in the sense that τ_x is smaller between 1932 and 1939 than it is in 1929. Note that this investment wedge pattern does not square with models of business cycles in which financial frictions worsen in downturns and improve in recoveries.

In Figure 2, we plot the 1929–39 data for U.S. output, labor, and investment along with the model's predictions for those variables. Note that labor declines 27% from 1929 to 1933 and stays relatively low for the rest of the decade. Investment also declines sharply from 1929 to 1933 but partially recovers by the end of the decade. Interestingly, in an algebraic sense, about half of output's 36% fall from 1929 to 1933 is due to the decline in investment.

In terms of the model, we start by assessing the separate contributions of the three wedges. In Figure 2, in addition to the data, we plot the values of output, labor, and investment that the model predicts are due to the efficiency wedge and the labor wedge. That is, we plot these variables using the efficiency component s_{1t} and the labor component s_{2t} for the wedges.

Consider the contribution of the efficiency wedge. In Figure 2, we see that with this wedge the model predicts that output declines less than it actually does in the data and that it recovers more rapidly. For example, by 1933, predicted output falls about 25% while U.S. output falls about 36%. Thus, the efficiency wedge accounts for about two-thirds of the decline of output in the data. By 1939, predicted output is only 3% below trend rather than the observed 22%. As can also be seen in Figure 2, the reason for this predicted rapid recovery is that the efficiency wedge accounts for only a small part of the observed movements in labor in the data. By 1933 the fall in predicted investment is similar to that in the data.

It recovers faster, however.

Consider next the contributions of the labor wedge. In Figure 2, we see that by 1933, the predicted output due to the labor wedge falls only about half as much as output falls in the data: 18% vs. 36%. By 1939, however, the labor wedge model's predicted output completely captures the slow recovery: it predicts output falling 22%, exactly as output does that year in the data. This model captures the slow output recovery because predicted labor due to the labor wedge also captures the sluggishness in labor after 1933 remarkably well. The associated prediction for investment is a decline, but not the actual sharp decline from 1929 to 1933.

Summarizing Figure 2, we can say that the efficiency wedge accounts for about two-thirds of output's downturn during the Great Depression but misses its slow recovery, while the labor wedge accounts for about one-half of this downturn and essentially all of the slow recovery.

Now consider the investment wedge. In Figure 3, we again plot the data for output, labor, and investment, but this time along with the contributions to those variables that the model predicts are due to the investment wedge. This figure demonstrates that the investment wedge's contributions completely miss the observed movements in all three variables. The investment wedge actually leads output to rise by about 7% by 1933.

Notice, since the effects of government consumption are small, that the sum of the output changes from 1929 to 1933 due to the three wedges – efficiency (−25%), labor (−18%), and investment (+7%) – is approximately the same as that in the data (−36%).

Together, then, Figures 2 and 3 suggest that the efficiency and labor wedges account for essentially all of the movements of output, labor, and investment in the Depression period and that the investment wedge accounts for almost none. This suggestion is confirmed by Figure 4. There we plot the sum of the contributions from the efficiency, labor, and (insignificant) government consumption wedges (labeled Model With No Investment Wedge). As can be seen from the figure, essentially all of the fluctuations in output, labor, and investment can be accounted for by movements in the efficiency and labor wedges. For comparison, we also plot the sum of the contributions due to the labor, investment, and government consumption wedges (labeled Model With No Efficiency Wedge). This sum does not do well. In fact, comparing Figures 2 and 4, we see that the model with this sum is further from the data than the model with the labor wedge component alone.

One issue of possible concern with our model with no efficiency wedge is that we mismeasure the investment wedge. Recall that the measurement of this wedge depends on the details of the stochastic process governing the wedges, whereas the size of the other wedges can be inferred from static equilibrium conditions. To address this issue, we conduct an experiment intended to give the model with no efficiency wedge the best chance of accounting for the data.

In this experiment, we set the labor and the government consumption wedges equal to their measured values and choose the investment wedge to be as large as it needs to be so that output in the model is as close as possible to output in the data, subject to the constraint that investment be nonnegative. This model (labeled Model With Maximum Investment Wedge) turns out to poorly match the behavior of consumption in the data. For example, from 1929 to 1933, consumption in the model declines about 7% relative to trend while consumption in the data declines about 28%. We label this poor performance the consumption anomaly of the investment wedge model.

In terms of consumption, the model with maximum investment wedge performs much worse than does the model with no investment wedge, in which the associated consumption decline is 23%. This finding suggests that models with nontrivial investment wedges are likely to work well only for downturns in which consumption declines are relatively small compared to the output decline.

Altogether, these findings lead us to conclude that distortions manifested as investment wedges played essentially no useful role in accounting for the U.S. Great Depression.

c. . . . And the 1982 Recession

Now we apply our accounting procedure to a more typical U.S. business cycle: the recession of 1982. We find that here, in terms of output and investment, the efficiency wedge plays a central role, the labor wedge does not, and the investment wedge actually moderates what would otherwise have been a more severe recession.

We start as we did in the Great Depression analysis, by displaying the actual U.S. output over the business cycle period – here, 1979–85 – along with the three measured wedges for that period. In Figure 5, we see that output falls nearly 10% relative to trend between 1979 and 1982 and by 1985 is back up to about 1% below trend. We also see that the efficiency wedge falls between 1979 and 1982 and by 1985 is still a little more than 2% below trend. The labor wedge also worsens from 1979 to 1982, but it improves substantially by 1985. The investment wedge, meanwhile, improves fairly steadily over the whole period.

An analysis of the effects of the wedges separately for the 1979–85 period is in Figures 6 and 7. In Figure 6, we see that the model with the efficiency wedge produces a decline in output from 1979 to 1982 of 13%, which is more than the actual decline in that period. With the efficiency wedge, output recovers but not as rapidly as in the data. In contrast, the model with the labor wedge accounts for little of the output fluctuations. In Figure 7, we see that the model with just the investment wedge actually produces an increase in output of roughly 10% from 1979 to 1982.

Now we examine how well a combination of wedges reproduces the data for the 1982 recession period. In Figure 8, we plot the movements in output, labor, and investment during 1979–85 due to two combinations of wedges. One is the sum of the e ciency, labor, and (insignificant) government consumption components (labeled Model With No Investment Wedge). In terms of output, this sum declines about 18% by 1982, about twice as much as the data, and by 1985 it is still well below the data. The other is the sum of the labor, investment, and government components (labeled Model With No E ciency Wedge), which produces a rise in output rather than a recession. These findings suggest that distortions corresponding to investment wedges actually prevented the downturn from being even deeper than it was.

2.3. Extending the Analysis to the Entire Postwar Period

So far we have analyzed the wedges and their contributions for specific episodes. Now we attempt to extend our analysis to the entire postwar period by developing some summary statistics for the period from 1959:1 through 2004:3 using HP-filtered data. We first consider the standard deviations of the wedges relative to output as well as correlations of the wedges with each other and with output at various leads and lags. We then consider the standard deviations and the cross correlations of output due to each wedge. These statistics summarize salient features of the wedges and their role in output fluctuations for the entire postwar sample. We think of the wedge statistics as analogs of our plots of the wedges, and the output statistics as analogs of our plots of output due to just one wedge.[1] The results for this long historical period turn out to be consistent with those for the two specific episodes.

In Tables II and III, we display standard deviations and cross correlations calculated using HP-filtered data. Panel A of Table II shows that the e ciency wedge and the labor wedge are positively correlated with output, both contemporaneously and for several leads and lags. The investment wedge and government consumption wedge, meanwhile, are negatively correlated with output, both contemporaneously and for several leads and lags. (Note that the government consumption wedge is the sum of government consumption and net exports and that net exports are negatively correlated with output.) Panel B of Table II shows that the e ciency and labor wedges are positively correlated while the cross correlations of the other combinations of wedges are nearly all negative.

Table III summarizes various statistics of the movements of output due to each wedge. Consider first the output fluctuations due to the e ciency wedge. Table III shows that output movements due to

[1] In Chari, Kehoe, and McGrattan (2004), we apply a spectral method to determine the contributions of the wedges based on the population properties of the stochastic process generated by the model. We do this in both periods and find that the investment wedge plays only a modest role.

this wedge have a standard deviation relative to output in the data of 1.49 and that output movements due to the wedge are highly positively correlated with output in the data, both contemporaneously and for several leads and lags. These statistics are consistent with the episodic analysis of the 1982 recession, which showed that output due to the efficiency wedge both fluctuates substantially more than output and comoves highly with it.

Consider next the role of the other wedges. Output due to the labor wedge fluctuates about half as much as output in the data and is positively correlated with it. Output due to the investment wedge fluctuates three-quarters as much as output in the data but is highly negatively correlated with it. Finally, output due to the government consumption wedge fluctuates about half as much as output in the data and is modestly negatively correlated with it. In panel B of Table III we see that output movements due to the efficiency and labor wedges are positively correlated and the cross correlations of output movements due to the other wedges are nearly all negative.

The main point we draw from these summary statistics is the same point we drew from our earlier analyses: models in which the driving forces of business cycles are frictions that manifest themselves primarily as investment wedges are not promising. In fact, the statistics show that recessions in such models will be associated with booms in the data.

Another point we draw from the summary statistics is about efficiency wedges. Our decomposition of business cycle fluctuations implies that efficiency wedges play a much larger role in driving fluctuations in output than much of the literature has found. Our decomposition differs from that in the early literature on business cycles in two ways, one quantitatively important and one not. The quantitatively important difference is that we allow for multiple correlated shocks, while most of the early literature focuses on models with a single shock. The other difference is that our decomposition is based on realizations, not a population.

To demonstrate the quantitative importance of our shock structure, we analyze a version of our model with only an efficiency wedge. Specifically, we consider the properties of the output component when the efficiency wedge follows a first-order autoregressive process of the form

$$\log A_{t+1} = (1-\rho)\log \bar{A} + \rho \log A_t + \varepsilon_{At+1}.$$

Note that our realization-based decomposition of the log-linearized model is independent of the variance of the shock ε_{At}. In line with the univariate specifications in the literature, we vary the autoregressive parameter ρ between .95 and .99. As we do, the standard deviation of output in the model relative to that in the data varies from .90 to .72. These statistics are similar to those in the early literature, which depend on population-based decompositions. This finding leads us to conclude that the main source of our di erent result about e ciency wedges is that we have multiple correlated shocks instead of just one.

3. Contrasting Our Decomposition With Traditional Decompositions

Our decomposition is intended to isolate the partial e ects of each of the wedges on equilibrium outcomes, and in this sense, it is di erent from traditional decompositions. Those decompositions attempt to isolate the e ects of (so-called) primitive shocks on equilibrium outcomes; ours does not. Isolating the e ects of primitive shocks requires specifying a detailed model. Since our procedure precedes the specification of a detailed model, it obviously cannot be used to isolate the e ects of primitive shocks.

In order to clarify the distinction between our decomposition and a traditional one, here we describe a traditional decomposition and explain why we prefer ours. The traditional decomposition attempts to isolate the e ects of primitive shocks by “naming the innovations.” Recall that in our stochastic process for the four wedges, (26), the innovations ε_{t+1} are allowed to be contemporaneously correlated with covariance matrix V. Under the traditional decomposition, the primitive shocks, say, η_{t+1}, are assumed to be mean zero, to be contemporaneously uncorrelated with $E\eta_{t+1}\eta_{t+1}' = I$, and to lead to the same stochastic process for the wedges. Identifying these primitive shocks requires specifying a matrix R so that $R\eta_{t+1} = \varepsilon_{t+1}$ and $RR' = V$. Names are then made up for these shocks, including money shocks, demand shocks, financial friction shocks, and so on.

In the traditional method, then, given any sequence of realized wedges s_t, the associated realized values of $\eta_t = (\eta_{1t}, \eta_{2t}, \eta_{3t}, \eta_{4t})'$ are computed. The movements in, say, output, are then decomposed into the movements due to each one of these primitive shocks as follows. Let $s_t(\eta_1) = (\log A_t(\eta_1), \tau_{lt}(\eta_1), \tau_{xt}(\eta_1), \log g_t(\eta_1))$ denote the realized values of the four wedges when the primitive shock sequence $\eta_t = (\eta_{1t}, 0, 0, 0)$ is fed into

$$s_{t+1} = P_0 + P s_t + R\eta_{t+1}.$$

(Note that when the covariance matrix V is not diagonal, movements in a primitive shock η_{1t} will lead to movements in more than one wedge.) The predicted value of, say, output due to η_1 is then computed from the decision rules of the model according to $y_t(\eta_1) = y(k_t(\eta_1), s_t(\eta_1))$, where $k_t(\eta_1)$ is computed recursively using the decision rule for investment, the initial capital stock, and the capital accumulation law. The values $s_t(\eta_2)$, $y_t(\eta_2)$, and the rest are computed in a similar fashion.

Notice that in this decomposition method, the realized value of each wedge is simply the sum of the parts due to η_1, η_2, and so on, in that

$$\log A_t = \sum_i \log A_t(\eta_i), \;\; \tau_{lt} = \sum_i \tau_{lt}(\eta_i), \;\; \tau_{xt} = \sum_i \tau_{xt}(\eta_i), \;\; \log g_t = \sum_i \log g_t(\eta_i).$$

In this sense, the traditional decomposition attempts to decompose each of the four wedges into four component parts, each of which is due to a primitive shock.

Our decomposition is purposefully less ambitious. It includes only the e ect of the movements of each total wedge, not any of its subparts. The advantage of our decomposition is that it is invariant to R, so that the method does not need to make up the matrix R, nor do we need to make up the names for the shocks. This invariance makes our method valuable.

The traditional decomposition is not useful for guiding the development of detailed models because it requires putting the cart before the horse: the decomposition requires specifying the matrix R, but doing that requires a detailed model. Our decomposition is useful precisely because it does not need the matrix R. Moreover, in our view in constructing models, studying the pattern of wedges and their e ects is more fruitful than studying the e ects of so-called primitive shocks.

4. Exploring Sensitivity to Alternative Specifications

Here we investigate whether our results are substantially changed when we use some alternative specifications of the prototype model. We find that they are not.

4.1. Motivation and Summary

One reasonable question about our results is the extent to which they rely on the specific stochastic process driving the wedges. To answer that question, we have attempted several alternative specifications of that process. Our substantive findings are essentially una ected by these changes.

In the accounting exercise with our benchmark model, we have made three assumptions that could reasonably be conjectured as being important for our results. We have assumed that the capital utilization rate is fixed; that preferences have a particular functional form, that is, logarithmic, in both consumption and leisure; and that adjusting investment in the economy is costless. Some researchers have argued against all of these assumptions, arguing that capital utilization rates fluctuate systematically over the business cycle, that labor supply is less elastic than in our specification, and that including positive adjustment costs is essential to understand investment behavior. If those arguments are correct, then our procedure mismeasures the wedges. If capital utilization rates fluctuate systematically, then our procedure mismeasures the e ciency wedge; if labor supply is less elastic than we have assumed, then our procedure mismeasures the labor wedge; and if investment adjustment costs matter, then our procedure mismeasures the investment wedge. Here we demonstrate that changing these assumptions has little e ect on our findings.

We examine the effect of these alternative assumptions one by one, first quantitatively and then intuitively, by proving some propositions that help explain the results. The changes turn out to produce offsetting effects, leaving our original results unchanged. Allowing for variable capital utilization decreases the variability of the efficiency wedge and increases that of the labor wedge. This change in the relative variability of the two wedges does change the relative amounts of the business cycle movements separately accounted for by these wedges. However, the relative variability change has almost no effect on the sum of the contributions due to the two wedges and, thus, also essentially none on the amount of fluctuations accounted for by the investment wedge. As such, allowing for variable capital utilization does not alter our conclusion that investment wedges played almost no role in the Great Depression or the 1982 recession. Similarly, reducing the elasticity of the labor supply increases the variability of the labor wedge. But that increased variability of labor is offset by the reduced responsiveness to it, and the overall effect is minimal. Finally, allowing for investment adjustment costs effectively rescales the investment wedge but does little else quantitatively.

These findings suggest that alone the sizes of the measured wedges are not informative for assessing competing business cycle models. The three examples of alternative specifications in this section show that the equilibrium responses of models can be quite similar even though the sizes of the wedges are quite different. Constructing examples in which two models have similar-sized wedges but very different equilibrium responses should be easy. The lesson we draw from our results is that competing business cycle models should be assessed by the equilibrium responses to the wedges, not by the size of the wedges.

4.2. Details of Alternative Specifications

a. Variable Capital Utilization

Here we consider an extreme view about the amount of variability in capital utilization and show that this change does not alter the main conclusion that models which emphasize the investment wedge are not promising.

Our alternative specification of the technology which allows for variable capital utilization follows the work of Kydland and Prescott (1988) and Hornstein and Prescott (1993). We assume that the production function is now

(28) $y = A(kh)^{\alpha}(nh)^{1-\alpha}$,

where n is the number of workers employed and h is the length (or hours) of the workweek. The labor input is, then, $l = nh$.

In the data, we measure only the labor input l and the capital stock k. We do not directly measure h or n. The benchmark specification for the production function can be interpreted as assuming that all of the observed variation in measured labor input l is in the number of workers and that the workweek h is constant. Under this interpretation, our benchmark specification with fixed capital utilization correctly measures the efficiency wedge (up to the constant h).

Here we investigate the opposite extreme: assume now that the number of workers n is constant and that all the variation in labor is from the workweek h. Under this variable capital utilization specification, the services of capital kh are proportional to the product of the stock k and the labor input l, so that variations in the labor input induce variations in the flow of capital services. Thus, the capital utilization rate is proportional to the labor input l, and the efficiency wedge is proportional to y/k^{α}.

In Figure 9, we plot the measured efficiency wedges for these two specifications of capital utilization during the Great Depression period. Clearly, the efficiency wedge falls less and recovers more by 1939 when capital utilization is variable than when it is fixed. We do not plot either the labor wedge or the investment wedge because they are identical, up to a scale factor, in the two specifications.

In Figure 10, we plot the data and the predicted output due to the efficiency and labor wedges for the 1930s when the model includes variable capital utilization. Comparing Figures 10 and 2, we see that with the remeasured efficiency wedge, the labor wedge plays a much larger role in accounting for the output downturn and slow recovery and that the efficiency wedge plays a much smaller role.

In Figure 11, we plot the three data series again, this time with the predictions of the variable capital utilization model with just the investment wedge. We see that with variable capital utilization, the investment wedge still drives output the wrong way.

In Figure 12, we compare the contributions of the sum of the efficiency and labor wedges for the two specifications of capital utilization (fixed and variable). The figure shows that these contributions are quite similar. While remeasuring the efficiency wedge changes the relative contributions of the two wedges, it clearly has little effect on their combined contribution. Taking account of variable capital utilization thus does not change the basic result that in the Great Depression period, the efficiency and labor wedges played a central role and that models that emphasize the investment wedge are not promising.

Our findings suggest a more general result with regard to capital utilization: if investment wedges account for only a small fraction of fluctuations when capital utilization is fixed, then this fraction will also be small when it varies. Here we prove a proposition that provides a theoretical rationale for such a result in the extreme case in which the contribution of the investment wedge to fluctuations is zero.

Consider an economy identical to a deterministic version of our benchmark model except that the production function is now given by $y = Ak^{\alpha}l^{\gamma}$. Note that setting $\gamma = 1 - \alpha$ yields our benchmark model, while setting $\gamma = 1$ yields the variable capital utilization model. Let there be two such economies, indexed by $i = 1, 2$, with γ equal to γ_1 and γ_2, respectively, and the same initial capital stocks. For some given sequence of wedges $(A_{1t}, \tau_{l1t}, \tau_{x1t})$, let y_{1t}, c_{1t}, l_{1t}, and x_{1t} denote the resulting equilibrium outcomes in the economy with $\gamma = \gamma_1$. We then have this proposition:

Proposition 3: If the sequence of wedges for economy 2 is given by $A_{2t} = A_{1t}l_{1t}^{(\gamma_1 - \gamma_2)}$, $1 - \tau_{l2t} = \gamma_1(1 - \tau_{l1t})/\gamma_2$, and $\tau_{x2t} = \tau_{x1t}$, then the equilibrium outcomes y_{2t}, c_{2t}, l_{2t}, and x_{2t} for this economy coincide with the equilibrium outcomes y_{1t}, c_{1t}, l_{1t}, and x_{1t} for economy 1.

Proof: We prove this proposition by showing that the equilibrium conditions of economy 2 are satisfied at the equilibrium outcomes of economy 1. Since $y_{1t} = A_{1t}k_{1t}^{\alpha}l_{1t}^{\gamma_1}$, using the definition of A_{2t}, we have that $y_{1t} = A_{2t}k_{1t}^{\alpha}l_{1t}^{\gamma_2}$. The first-order condition for labor in economy 1 is

$$-\frac{U_{lt}(c_{1t}, l_{1t})}{U_{ct}(c_{1t}, l_{1t})} = (1 - \tau_{l1t})\frac{\gamma_1 y_{1t}}{l_{1t}}.$$

Using the definition of τ_{l2t}, we have that

$$-\frac{U_{lt}(c_{1t}, l_{1t})}{U_{ct}(c_{1t}, l_{1t})} = (1 - \tau_{l2t})\frac{\gamma_2 y_{1t}}{l_{1t}}.$$

The rest of the equations governing the equilibrium are unaffected. Q.E.D.

This proposition implies that if τ_{x1t} is a constant, so that the contribution of the investment wedge to fluctuations in economy 1 is zero, then τ_{x2t} is also a constant; hence, the contribution of the investment wedge to fluctuations in economy 2 is also zero. Extending this proposition to a stochastic environment is immediate.

Notice from Proposition 3 that the size of the measured wedges will be different when the labor exponents, γ_1 and γ_2, are different, but the outcomes will be the same. To understand why, consider the following thought experiment. Generate data from economy 1 and measure the wedges using the parameter values from economy 2. If these measured wedges are fed back into economy 2, then the data generated from economy 1 will be recovered.

b. Different Labor Supply Elasticities

Now we consider the effects on our results if another specification is changed: the elasticity of labor supply. We had assumed in our benchmark model that preferences are logarithmic in both consumption and leisure. Assume now that the labor elasticity is smaller than we had assumed. We show that for two economies with differing labor supply elasticities, a result analogous to that in Proposition 3 holds: allowing for different labor supply elasticities changes the size of the measured labor wedge but does not change the measured investment wedge. Therefore, if the contribution of the investment wedge is zero in an economy with a higher labor supply elasticity, it is also zero in an economy with a lower labor supply elasticity.

To see that, consider two economies identical to a deterministic version of our benchmark model except that now the utility function is given by

$$U(c) + V_i(1 - l)$$

for $i = 1, 2$. In our benchmark model, both U and V_i are logarithmic. Clearly, by varying the function V_i, we can generate a wide range of alternative labor supply elasticities.

For some given sequence of wedges $(A_{1t}, \tau_{l1t}, \tau_{x1t})$, let y_{1t}, c_{1t}, l_{1t}, and x_{1t} denote the resulting equilibrium outcomes in economy 1. Let the initial capital stocks be the same in economies 1 and 2. We then have this proposition:

PROPOSITION 4: If the sequence of wedges for economy 2 is given by

$$1 - \tau_{l2t} = (1 - \tau_{l1t})\frac{V_2'(1 - l_{1t})}{V_1'(1 - l_{1t})},$$

and if $A_{2t} = A_{1t}$ and $\tau_{x2t} = \tau_{x1t}$, then the equilibrium outcomes for economy 2 coincide with those of economy 1.

PROOF: We prove this proposition by showing that the equilibrium conditions of economy 2 are satisfied at the equilibrium outcomes of economy 1. The first-order condition for labor input in economy 1 is

$$-\frac{V_1'(1 - l_{1t})}{U'(c_{1t})} = (1 - \tau_{l1t})\frac{(1 - \alpha)y_{1t}}{l_{1t}}.$$

Using the definition of τ_{l2t}, we have that

$$-\frac{V_2'(1 - l_{1t})}{U'(c_{1t})} = (1 - \tau_{l2t})\frac{(1 - \alpha)y_{1t}}{l_{1t}},$$

so that the first-order condition for labor in economy 2 is satisfied. The rest of the equations governing the equilibrium are unaffected. Q.E.D.

The investment wedges are the same in both economies. Thus, if the investment wedge is constant in one economy, it is constant in the other; and the contribution of the investment wedge to fluctuations is zero in both economies. Extending this proposition to a stochastic environment is immediate.

c. Investment Adjustment Costs

Now we consider one more specification change: extending the benchmark prototype model to allow for investment adjustment costs. This extension does not substantially change our results either.

Investment adjustment costs can be interpreted in at least two ways. One is that these costs are part of the technology for converting output into installed capital. As shown by Chari, Kehoe, and McGrattan (2004), another interpretation is that financial frictions as in Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997) manifest themselves as adjustment costs in a prototype model.

With investment adjustment costs, the capital accumulation law is no longer (1) but rather

(29) $$(1+\gamma_n)k_{t+1} = (1-\delta)k_t + x_t - \varphi\left(\frac{x_t}{k_t}\right)k_t,$$

where φ represents the per unit cost of adjusting the capital stock. In the macroeconomics literature, a commonly used functional form for the adjustment costs φ is

(30) $$\varphi\left(\frac{x}{k}\right) = \frac{a}{2}\left(\frac{x}{k} - \delta - \gamma - \gamma_n\right)^2,$$

where $\delta + \gamma + \gamma_n$ is the steady-state value of the investment-capital ratio.

We follow Bernanke, Gertler, and Gilchrist (1999) in how we choose the value for the parameter a. Bernanke, Gertler, and Gilchrist choose this parameter so that the elasticity, η, of the price of capital with respect to the investment-capital ratio is .25. In this setup, the price of capital $q = 1/(1-\varphi')$, so that, evaluated at the steady state, $\eta = a(\delta+\gamma+\gamma_n)$. Given our other parameters, $a = 3.22$. In Figure 13, this parameterization is labeled as the model with Costs at BGG level. Bernanke, Gertler, and Gilchrist also argue that a reasonable range for the elasticity η is between 0 and .5 and that values much outside this range imply implausibly high adjustment costs. We consider an extreme case in which $\eta = 1$, so that $a = 12.88$. In the figure, this parameterization is labeled as the model with Costs at 4 times BGG level.

Here we focus on the results for the Great Depression period. In Figure 13, we plot the wedges for the benchmark model (labeled Wedges, No Costs), as well as the two models with adjustment costs. In Figure 14, we plot the three models' predicted values for output, labor, and investment due to the investment wedge alone. These figures show that introducing investment adjustment costs leads the investment wedge to worsen rather than improve in the early part of the Great Depression. This worsening produces a decline in output from 1929 to 1933. With the BGG adjustment costs, however, the decline is tiny (2% from 1929 to 1933). Even with the extreme adjustment costs, the decline is only 6% and, hence, accounts for about one-sixth of the overall decline in output.[2] Moreover, with these extreme adjustment

[2] In general, in our Great Depression experiments, linear methods perform poorly compared to our nonlinear method. With extreme adjustment costs, for example, linear methods produce large errors, on the order of 100%.

costs, the consumption anomaly associated with investment wedges is acute. For example, from 1929 to 1932, relative to trend, consumption in the data falls about 18%, while in the model it actually rises by over 6%.

In the model with extreme adjustment costs, the resources lost due to adjustment costs, as a fraction of output, are nearly 7% in 1933.[3] We share Bernanke, Gertler, and Gilchrist's (1999) concerns that costs of this magnitude are implausibly large. From 1929 to 1933, investment falls sharply, but the adjustment costs implied by (30) rise sharply. Why would firms be incurring adjustment costs simply because they were investing at positive rates below their steady-state value? The idea that managers were incurring huge adjustment costs simply because they were watching their machines depreciate seems far-fetched. Furthermore, the idea that from 1929 to 1933 investment fell sharply but adjustment costs rose sharply is inconsistent with interpreting these costs as arising from monitoring costs in an economy with financial frictions. Indeed, in such an economy, as investment activity falls, so do monitoring costs.

Finally, the use of adjustment costs in macroeconomic analysis is controversial. Kydland and Prescott (1982), for example, have argued that models with adjustment costs like those in (30) are inconsistent with the data. Such models imply a static relationship between the investment-capital ratio and the relative price of investment goods to output (of the form $q = 1/[1 - \varphi'(x/k)]$). This means that the elasticity of the investment-capital ratio with respect to the relative price is the same in the short and the long run. Kydland and Prescott argue that this is not consistent with the data. There, short-run elasticities are much smaller than long-run elasticities.

5. Reviewing the Related Literature

Our work here is related to the existing literature in terms of methodology and the interpretation of the wedges.

5.1. Methodology

Our basic method is to use restrictions from economic theory to back out wedges from the data, formulate stochastic processes for these wedges, and then put the wedges back into a quantitative general equilibrium model for an accounting exercise. This basic idea is at the heart of an enormous amount of work in the real business cycle theory literature. Prescott (1986), for example, asks what fraction of

[3] The drop in output due to adjustment costs can be approximately decomposed into two parts: the resources lost due to adjustment costs and the e ects from changing the investment wedge. We have shown that the resources lost due to adjustment costs are similar in magnitude to the decline in output. Hence, the e ects on output from changing the investment wedge are tiny. In our technical appendix we provide intuition for this result more generally.

the variance of output can plausibly be attributed to productivity shocks, which we have referred to as the efficiency wedge. Subsequent studies have expanded this general equilibrium accounting exercise to include a wide variety of other shocks. (See, for example, the studies in Cooley's 1995 volume.)

An important difference between our method and others is that we back out the labor wedge and the investment wedge from the combined consumer and firm first-order conditions, while most of the recent business cycle literature uses direct measures of labor and investment shocks. Perhaps the most closely related precursor of our method is McGrattan's (1991); she uses the equilibrium of her model to infer the implicit wedges. Ingram, Kocherlakota, and Savin (1997) advocate a similar approach.

5.2. Wedge Interpretations and Assessments

The idea that taxes of various kinds distort the relation between various marginal conditions is the cornerstone of public finance. Taxes are not the only well-known distortions; monopoly power by unions or firms is also commonly thought to produce a labor wedge. And the idea that a labor wedge is produced by sticky wages or sticky prices is the cornerstone of the new Keynesian approach to business cycles; see, for example, the survey by Rotemberg and Woodford (1999). One contribution of our work here is to show the precise mapping between the wedges and general equilibrium models with frictions.

Many studies have plotted one or more of the four wedges. The efficiency wedge has been extensively studied. (See, for example, Kehoe and Prescott (2002).) The labor wedge has also been studied. For example, Parkin (1988), Hall (1997), and Galí, Gertler, and López-Salido (2005) all graph and interpret the labor wedge for the postwar data. Parkin discusses how monetary shocks might drive this wedge. Hall discusses how search frictions might drive this wedge. Galí, Gertler, and López-Salido discuss a variety of interpretations, as do Rotemberg and Woodford (1991, 1999). Mulligan (2002a, b) plots the labor wedge for the United States for much of the 20th century, including the Great Depression period. He interprets movements in this wedge as arising from changes in labor market institutions and regulation, including features we discuss here. Cole and Ohanian (2002) plot the labor wedge for the Great Depression and offer interpretations similar to ours. The investment wedge has been investigated by McGrattan (1991), Braun (1994), Carlstrom and Fuerst (1997), and Cooper and Ejarque (2000).

6. Conclusions and Extensions

This study is aimed at applied theorists who are interested in building detailed, quantitative models of economic fluctuations. Once such theorists have chosen the primitive sources of shocks to economic activity, they need to choose the mechanisms through which the shocks lead to business cycle fluctuations. We have shown that these mechanisms can be summarized by their effects on four wedges in the standard growth model. Our business cycle accounting method can be used to judge which mechanisms are promising and which are not, thus helping theorists narrow their options. We view our method as an alternative to structural VARs, which have also been advocated as a way to identify promising mechanisms. (Elsewhere, in Chari, Kehoe, and McGrattan (2005), we argue that structural VARs have deficiencies that limit their usefulness.)

Here we have demonstrated how our method works by applying it to the Great Depression and to the 1982 U.S. recession. We have found that efficiency and labor wedges, in combination, account for essentially all of the decline and recovery in these business cycles; investment wedges play, at best, a minor role. These results hold in summary statistics of the entire postwar period and in alternative specifications of the growth model. We have also found that when we maximized the contribution of the investment wedge, the models display a consumption anomaly, in that they tend to produce much smaller declines in consumption during downturns than in the data. These findings together imply that existing models of financial frictions in which the distortions primarily manifest themselves as investment wedges can account for only a small fraction of the fluctuations in the Great Depression or more typical U.S. downturns. These findings are our primary substantive contribution.

Quite beyond the specific model of Bernanke and Gertler (1989), researchers have argued that frictions in financial markets are important for business cycle fluctuations (Bernanke (1983) and the motivation in Bernanke and Gertler (1989)). We stress that our findings do not contradict this idea. Indeed, we have shown that a detailed economy with input-financing frictions is equivalent to a prototype economy with efficiency wedges. In this sense, while existing models of financial frictions are not promising, new models in which financial frictions show up as efficiency and labor wedges are.

More generally, our results suggest that future theoretical work should focus on developing models which lead to fluctuations in efficiency and labor wedges. Many existing models produce fluctuations in labor wedges. The challenging task is to develop detailed models in which primitive shocks lead to fluctuations in efficiency wedges as well.

A narrower challenge is to untangle the direct and indirect effects of changes in wedges. Our procedure combines the direct effects of movements in a particular wedge with the indirect effects arising from expectations of changes in other wedges in the future. Consider, for example, the experiment in which we examine the role of the efficiency wedge alone. There we feed into the model the actual path for the efficiency wedge and set all other wedges at their initial values. In the model, the agents' expectations about the evolution of future wedges are derived from the stochastic process for the wedges. Since our wedges are correlated with each other at various leads and lags, a movement in the e ciency wedge induces changes in expectations in the size of future e ciency and other wedges. Agents' decisions, in turn, respond both to the direct e ect of changes in current and future expected e ciency wedges and to the indirect e ect of changes in the expected values of other wedges. A useful extension of our work here would be to decompose the overall e ects into the direct and indirect e ects.

Another useful extension would be to decompose our wedges into the portion arising from explicit taxes imposed by governments and the portion that comes from frictions in detailed models. This decomposition would be particularly useful in situations where explicit taxes vary significantly over the cycle.

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APPENDIX: The Mapping for Two Other Wedges

Here we demonstrate the mapping from two other detailed economies with frictions to two prototype economies with wedges. In the preceding text, we have described the mapping for e ciency and labor wedges. In this appendix, we describe it for investment and government consumption wedges.

A. Investment Wedges Due to Investment Frictions

We start with the mapping of financial frictions to investment wedges.

In Chari, Kehoe, and McGrattan (2004), we show the equivalence between the Carlstrom and Fuerst (1997) model and a prototype economy. Here we focus on the financial frictions in the Bernanke, Gertler, and Gilchrist (1999) model and abstract from the monetary features of their model. Bernanke, Gertler, and Gilchrist begin by deriving the optimal financial contracts between risk-neutral entrepreneurs and financial intermediaries in an environment with no aggregate uncertainty. These contracts resemble debt contracts (with default). Bernanke, Gertler, and Gilchrist try to extend their derivation of optimal contracts to an economy with aggregate uncertainty. The contracts they consider are not optimal given the environment, because these contracts do not allow risk sharing between risk-averse consumers and risk-neutral entrepreneurs. Here we solve for optimal debt-like contracts that arbitrarily rule out such risk sharing, but even so, our first-order conditions di er from those of Bernanke, Gertler, and Gilchrist. (One reason for this di erence is that our break-even constraint for the financial intermediary and our law of motion for entrepreneurial net worth di er from theirs. See equations (32) and (34) below.)

a. A Detailed Economy With Financial Frictions

The Bernanke-Gertler-Gilchrist model has a continuum of risk-neutral entrepreneurs of mass L_e, a continuum of consumers of mass 1, and a representative firm. Output $y(s^t)$ is produced according to

$$(31)\qquad y(s^t) = A(s^t)k^\alpha \left[l^\Omega L_e^{1-\Omega}\right]^{1-\alpha},$$

where $A(s^t)$, k, and l are the technology shock, the capital stock, and the labor supplied by consumers. The stochastic process for the technology shocks is given by $\log A(s^{t+1}) = (1-\rho_A)\log A + \rho_A \log A(s^t) + \varepsilon_A(s^{t+1})$. Each entrepreneur supplies one unit of labor inelastically. The representative firm's maximization problem is to choose l, L_e, k to maximize profits $A(s^t)k^\alpha\left[l^\Omega L_e^{1-\Omega}\right]^{1-\alpha} - w(s^t)l - w_e(s^t)L_e - r(s^t)k$, where $w(s^t)$, $w_e(s^t)$, and $r(s^t)$ denote the wage rate for consumers, the wage rate for entrepreneurs, and the rental rate on capital.

New capital goods can be produced only by entrepreneurs. Each entrepreneur owns a technology that transforms output and old capital at the end of any period into capital goods at the beginning of the following period. In each period t, each entrepreneur receives an idiosyncratic shock ω drawn from a distribution $F(\omega)$ with expected value 1. This shock is i.i.d. across entrepreneurs and time. The realization of ω is private information to the entrepreneur. An entrepreneur who buys $k(s^{t-1})$ units of goods in period $t-1$ produces $\omega k(s^{t-1})$ units of capital at the beginning of period t. These capital goods are sold at price $R_k(s^t) = r(s^t) + (1-\delta)$, where δ is the rate of depreciation of the capital goods.

Entrepreneurs finance the production of new capital goods partly with their own net worth, $n(s^{t-1})$, and partly with loans from financial intermediaries. These intermediaries o er contracts with the following cuto form: in all idiosyncratic states at t in which $\omega \geq \bar{\omega}(s^t)$, the entrepreneur pays $\bar{\omega}(s^t)R_k(s^t)k(s^{t-1})$ and keeps $(\omega-\bar{\omega}(s^t))R_k(s^t)k(s^{t-1})$. In all other states, the entrepreneur receives nothing while the financial intermediary receives $\omega R_k(s^t)k(s^{t-1})$ net of monitoring costs $\mu\omega R_k(s^t)k(s^{t-1})$. We assume that financial intermediaries make zero profits in equilibrium.

Given an entrepreneur's net worth $n(s^{t-1})$, the contracting problem for a representative entrepreneur is to choose the cuto $\bar{\omega}(s^t)$ for each state and the amount of goods invested $k(s^{t-1})$ to maximize the expected utility of the entrepreneurs,

$$\sum \pi(s^t|s^{t-1})\{[(1-\Gamma(\bar{\omega}(s^t))]R_k(s^t)k(s^{t-1})\, dF(\omega)\},$$

subject to a break-even constraint for the intermediary,

$$\sum (s^t|s^{t-1})[\Gamma(\bar{\omega}(s^t)) - \mu G(\bar{\omega}(s^t))]R_k(s^t)k(s^{t-1}) = k(s^{t-1}) - n(s^{t-1}), \tag{32}$$

where $\Gamma(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega)\, d\omega + \bar{\omega}\int_{\bar{\omega}}^{\infty} f(\omega)\, d\omega$ and $G(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega)\, d\omega$. Here $q(s^t|s^{t-1})$ denotes the price of consumption goods in state s^t in units of consumption goods in state s^{t-1}.

This formulation implies an aggregation result: The capital demand of the entrepreneurs is linear in their net worth, so that total demand for goods from them depends only on their total net worth. The solution to the contracting problem is characterized by the first-order conditions with respect to $k(s^{t-1})$ and $\bar{\omega}(s^t)$, which can summarized by

$$\frac{\sum \pi(s^t|s^{t-1})[1-\Gamma(\bar{\omega}(s^t))]R_k(s^t)}{\sum \pi(s^t|s^{t-1})\Gamma'(\bar{\omega}(s^t))R_k(s^t)} = \frac{\sum q(s^t|s^{t-1})[\Gamma(\bar{\omega}(s^t)) - \mu G(\bar{\omega}(s^t))]R_k(s^t) - 1}{\sum q(s^t|s^{t-1})[\Gamma'(\bar{\omega}(s^t)) - \mu G'(\bar{\omega}(s^t))]R_k(s^t)} \tag{33}$$

and the break-even constraint (32).

In each period, a fraction γ of existing entrepreneurs dies and is replaced by a fraction γ of newborn entrepreneurs. At the beginning of each period, entrepreneurs learn whether they will die this period. We assume that γ is su ciently small and the technology for producing investment goods is su ciently productive so that entrepreneurs consume their net worth only when they are about to die. All entrepreneurs who are going to die consume their entire net worth and do not supply labor in the current period. (The newborn replacements do instead.) Those entrepreneurs who do not die save their wage income plus their income from producing capital goods. The aggregate income of the entrepreneurs is, then,

$$\int \left[\omega - \bar{\omega}(s^t)\right] R_k(s^t)k(s^{t-1})\, dF(\omega) + w_e(s^t)L_e,$$

where $k(s^{t-1})$ is the aggregate capital stock. The law of motion for aggregate net worth is given by

$$n(s^t) = \gamma \int \left[\omega - \bar{\omega}(s^t)\right] R_k(s^t)k(s^{t-1})\, dF(\omega) + w_e(s^t)L_e. \tag{34}$$

Total consumption by entrepreneurs in any period is

$$c_e(s^t) = (1-\gamma) \int \left[\omega - \bar{\omega}(s^t)\right] R_k(s^t)k(s^{t-1})\, dF(\omega). \tag{35}$$

Consumers maximize utility given by

$$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t)\, U(c(s^t), l(s^t)), \tag{36}$$

where $c(s^t)$ denotes consumption in state s^t subject to

$$c(s^t) + \sum_{s_{t+1}} q(s^{t+1}|s^t)b(s^{t+1}) \leq w(s^t)l(s^t) + b(s^t) + T(s^t), \tag{37}$$

for $t = 0, 1, \ldots$, and borrowing constraints, $b(s^{t+1}) \geq \bar{b}$, for some large negative number $\bar{b}$. Here $T(s^t)$ is lump-sum transfers. The initial condition $b(s^0)$ is given. Each of the bonds $b(s^{t+1})$ is a claim to one unit of consumption in state s^{t+1} and costs $q(s^{t+1}|s^t)$ dollars in state s^t. The first-order conditions for the consumer can be written as

$$(38)\qquad -\frac{U_l(s^t)}{U_c(s^t)} = w(s^t) \text{ and}$$

$$(39)\qquad q(s^{t+1}|s^t) = \beta\pi(s^{t+1}|s^t)\frac{U_c(s^{t+1})}{U_c(s^t)},$$

The market-clearing condition for final goods is then

$$c(s^t) + c_e(s^t) + \mu G(\bar{\omega}(s^t))R_k(s^t)k(s^{t-1}) + k(s^t) - (1-\delta)k(s^{t-1}) = y(s^t).$$

b. The Associated Prototype Economy With Investment Wedges

Now consider a prototype economy which is the same as our benchmark prototype economy, except for the following changes. We assume that the production function is as in (31), with L_e interpreted as a fixed input rented from the government, and we assume that consumers are taxed on capital income but not on investment or labor income. With capital income taxes, the consumers' budget constraint is given by

$$c(s^t) + k(s^t) - (1-\delta)k(s^{t-1}) = w(s^t)l(s^t) + (1-\tau_k(s^t))r(s^t)k(s^{t-1}) + \delta\tau_k(s^t)k(s^{t-1}) + T(s^t),$$

where $\tau_k(s^t)$ is the tax rate on capital income. Here $\tau_k(s^t)$ plays the role of an investment wedge. The resource constraint for the prototype economy is as in the benchmark prototype economy. Let government consumption in the prototype economy be given by

$$(40)\qquad g(s^t) = c_e^*(s^t) + \mu G(\bar{\omega}^*(s^t))R_k^*(s^t)k^*(s^{t-1}),$$

where asterisks denote the allocations in the detailed economy with investment frictions.

We now show how the tax on capital income in our prototype economy can be constructed from the detailed economy. First, the break-even constraint in the detailed economy can be rewritten as

$$\sum q^*(s^t|s^{t-1})\left\{[\Gamma(\bar{\omega}^*(s^t)) - \mu G(\bar{\omega}^*(s^t))]R_k^*(s^t) + \frac{n^*(s^{t-1})}{k^*(s^{t-1})}\frac{U_c^*(s^{t-1})}{\beta\pi(s^t|s^{t-1})U_c^*(s^t)}\right\} = 1,$$

where $q^*(s^t|s^{t-1}) = \beta\pi(s^t|s^{t-1})U_c^*(s^t)/U_c^*(s^{t-1})$. The intertemporal Euler equation in the prototype economy is

$$\sum q(s^t|s^{t-1})\{[(1-\tau_k(s^t)]A(s^t)F_k(s^t) + (1-\delta)\} = 1,$$

where $q(s^t|s^{t-1}) = \beta\pi(s^t|s^{t-1})U_c(s^t)/U_c(s^{t-1})$. Let the tax rate on capital income $\tau_k(s^t)$ be such that

$$(41)\qquad \begin{aligned} &[1-\tau_k(s^t)](A(s^t)F_k^*(s^t) - \delta) + 1 \\ &= [\Gamma(\bar{\omega}^*(s^t)) - \mu G(\bar{\omega}^*(s^t))]R_k^*(s^t) + \frac{n^*(s^{t-1})}{k^*(s^{t-1})}\frac{U_c^*(s^{t-1})}{\beta\pi(s^t|s^{t-1})U_c^*(s^t)}. \end{aligned}$$

Comparing first-order conditions for the two economies, we then have this proposition:

PROPOSITION 5: Consider the prototype economy just described, with government consumption given by (40) and capital income taxes by (41). The aggregate equilibrium allocations for this prototype economy coincide with those of the detailed economy with investment frictions.

B. Government Consumption Wedges Due to Net Exports

Now we develop a detailed economy with international borrowing and lending and show that net exports in that economy are equivalent to a government consumption wedge in an associated prototype economy.

a. A Detailed Economy With International Borrowing and Lending

Consider a model of a world economy with N countries and a single homogenous good in each period. We use the same notation for uncertainty as before.

The representative consumer in country i has preferences

$$\sum \beta^t \pi(s^t) U(c_i(s^t), l_i(s^t)), \tag{42}$$

where $c_i(s^t)$ and $l_i(s^t)$ denote consumption and labor. The consumer's budget constraint is

$$c_i(s^t) + b_i(s^t) + k_i(s^t) \le F\left(k_i(s^{t-1}), l_i(s^t)\right) + (1-\delta)k_i(s^{t-1}) + \sum_{s^{t+1}} q(s^{t+1}/s^t) b_i(s^{t+1}), \tag{43}$$

where $b^i(s^{t+1})$ denotes the amount of state-contingent borrowing by the consumer in country i in period t, $q(s^{t+1}/s^t)$ denotes the corresponding state-contingent price, and $k_i(s^t)$ denotes the capital stock.

An equilibrium for this detailed economy is a set of allocations $(c_i(s^t), k_i(s^t), l_i(s^t), b_i(s^{t+1}))$, and prices $q(s^t/s^{t-1})$ such that these allocations both solve the consumer's problem in each country i and satisfy the world resource constraint:

$$\sum_{i=1}^{N} [c_i(s^t) + k_i(s^t)] \le \sum_{i=1}^{N} [F\left(k_i(s^{t-1}), l_i(s^t)\right) + (1-\delta)k_i(s^{t-1})]. \tag{44}$$

Note that in this economy, the net exports of country i are given by

$$F(k_i(s^{t-1}), l_i(s^t)) - [k_i(s^t) - (1-\delta)k_i(s^{t-1})] - c_i(s^t).$$

b. The Associated Prototype Economy With Government Consumption Wedges

Now consider a prototype economy of a single closed economy i with an exogenous stochastic variable, government consumption $g_i(s^t)$, which we call the government consumption wedge. In this economy, consumers maximize (42) subject to their budget constraint

$$c_i(s^t) + k_i(s^t) = w_i(s^t) l_i(s^t) + \left[r_i(s^t) + 1 - \delta\right] k_i(s^{t-1}) + T_i(s^t), \tag{45}$$

where $w_i(s^t)$, $r_i(s^t)$, and $T_i(s^t)$ are the wage rate, the capital rental rate, and lump-sum transfers. In each state s^t, firms choose k and l to maximize $F(k, l) - r_i(s^t)k - w_i(s^t)l$. The government's budget constraint is

$$g_i(s^t) + T_i(s^t) = 0. \tag{46}$$

The resource constraint for this economy is

$$c_i(s^t) + g_i(s^t) + k_i(s^t) = F\left(k_i(s^{t-1}), l_i(s^t)\right) + (1-\delta)k_i(s^{t-1}). \tag{47}$$

An equilibrium of the prototype economy is, then, a set of allocations $(c_i(s^t), k_i(s^t), l_i(s^t), g_i(s^t), T_i(s^t))$, and prices $(w_i(s^t), r_i(s^t))$ such that these allocations are optimal for consumers and firms and the resource constraint is satisfied.

The following proposition shows that the government consumption wedge in this prototype economy consists of net exports in the original economy.

PROPOSITION 6: Consider the equilibrium allocations $(c_i^*(s^t), k_i^*(s^t), l_i^*(s^t), b_i^*(s^{t+1}))$ for country i in the detailed economy. Let the government consumption wedge be

$$(48) \qquad g_i(s^t) = F\left(k_i^*(s^{t-1}), l_i^*(s^t)\right) - \left[k_i^*(s^t) - (1-\delta)k_i^*(s^{t-1})\right] - c_i^*(s^t),$$

let the wage and capital rental rates be $w_i(s^t) = F_{li}^*(s^t)$ and $r_i(s^t) = F_{ki}^*(s^t)$, and let $T_i(s^t)$ be defined by (46). Then the allocations $(c_i^*(s^t), k_i^*(s^t), l_i^*(s^t), g_i^*(s^t), T_i(s^t))$ and the prices $(w_i(s^t), r_i(s^t))$ are an equilibrium for the prototype economy.

The proof follows by noting that the first-order conditions are the same in the two economies and that, given the government consumption wedge (48), the consumer's budget constraint (43) in the detailed economy is equivalent to the resource constraint (47) in the prototype economy.

Note that for simplicity we have abstracted from government consumption in the detailed economy. If that economy had government consumption as well, then the government consumption wedge in the prototype economy would be the sum of net exports and government consumption in the detailed economy.

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TABLE I

Parameters of Vector AR(1) Stochastic Process in Two Historical Episodes[a] Estimated Using Maximum Likelihood with U.S. Data[b]

A. Annual Data, 1901−40

Coefficient matrix P on lagged states

.804 (.544,1.05)	.0510 (−.0304,.145)	−.150 (−.561,.502)	0
−.0924 (−.362,.221)	1.05 (.870,1.10)	.538 (−.0466,.960)	0
−.0262 (−.468,.205)	−.0304 (−.226,.152)	.170 (−.310,.390)	0
0	0	0	.747 (.413,.805)

Coefficient matrix Q where $V = QQ'$

.0516 (.0381,.0622)	0	0	0
−.0154 (−.0309,.00544)	.0459 (.0231,.0548)	0	0
−.00725 (−.0394,.0167)	−.00471 (−.0193,.0123)	.0327 (.0093,.0429)	0
0	0	0	.221 (.145,.277)

Means of states = [.544 (.506, .595), −.186 (−.262, −.0800), .278 (.216, .355), −2.78 (−2.94, −2.53)]

B. Quarterly Data, 1959:1−2004:3[c]

Coefficient matrix P on lagged states

.764	.0455 (.0315,.0451)	.434 (.397,411)	−.0486 (−.0882,−.0433)
−.0236 (−.0392,−.0141)	.995 (.949,.995)	.0397 (.0298,.0475)	−.00442 (−.00758,.0121)
−.0958 (−.0899,−.0670)	.0240 (.0212,.0366)	1.17 (1.12,1.15)	−.0201 (−.0315,−.0170)
−.0254 (−.0384,−.00233)	.0398 (.0439,.0699)	.000948 (−.00333,.0185)	.992 (.973,.991)

Coefficient matrix Q where $V = QQ'$

.0125 (.00874,.0128)	0	0	0
−.00245 (−.00487,−.00245)	.00554 (.00108,.00443)	0	0
.00457 (.00219,.00419)	.000607 (−.000598,.00161)	.00185 (.000746,.00239)	0
−.00418 (.00870,−.00301)	.00436 (−.00288,.0108)	.0136 (.00472,.0132)	6.97e−7 (7.39e−9,1.87e−5)

Means of states = [−.0375 (−.0472, −.0223), .304 (.294, .316), .356 (.326, .359), −1.570 (−1.60, −1.56)]

[a] To ensure stationarity, we add a penalty term to the likelihood function proportional to $\max(|\lambda_{max}| - .995, 0)^2$, where λ_{max} is the maximal eigenvalue of P. Numbers in parentheses are 90 percent confidence intervals for a bootstrapped distribution with 500 replications. To ensure that the variance-covariance matrix V is positive semi-definite, we estimate Q rather than $V = QQ'$.

[b] Sources of basic data: See Chari, Kehoe, and McGrattan (2006).

[c] The (1,1) element of P is set residually after imposing the condition that one eigenvalue is equal to 0.995. This is done to achieve better performance in hill-climbing when we compute confidence intervals.

TABLE II

PROPERTIES OF THE WEDGES, 1959:1–2004:3[a]

A. SUMMARY STATISTICS

Wedges	Standard Deviation Relative to Output	Cross Correlation of Wedge with Output at Lag $k =$				
		−2	−1	0	1	2
Efficiency	.62	.65	.76	.85	.61	.35
Labor	.92	.52	.65	.71	.73	.68
Investment	.25	−.49	−.60	−.70	−.50	−.31
Government Consumption	1.51	−.42	−.42	−.33	−.24	−.11

B. CROSS CORRELATIONS

Wedges (X, Y)	Cross Correlation of X with Y at Lag $k =$				
	−2	−1	0	1	2
Efficiency, Labor	.57	.48	.30	.28	.17
Efficiency, Investment	−.34	−.59	−.85	−.61	−.37
Efficiency, Government Consumption	−.27	−.33	−.34	−.35	−.31
Labor, Investment	−.18	−.18	−.15	−.28	−.35
Labor, Government Consumption	−.02	−.22	−.38	−.47	−.50
Investment, Government Consumption	−.02	−.05	−.16	−.04	.01

[a] Series are first logged and detrended using the HP filter.

TABLE III

PROPERTIES OF THE OUTPUT COMPONENTS, 1959:1–2004:3[a]

A. SUMMARY STATISTICS

Output Components	Standard Deviation Relative to Output	Cross Correlation of Component with Output at Lag $k =$				
		−2	−1	0	1	2
Efficiency	1.49	.64	.77	.87	.63	.39
Labor	.60	.52	.67	.73	.76	.71
Investment	.74	−.47	−.59	−.70	−.52	−.34
Government Consumption	.55	−.44	−.45	−.38	−.29	−.15

B. CROSS CORRELATIONS

Output Components (X, Y)	Cross Correlation of X with Y at Lag $k =$				
	−2	−1	0	1	2
Efficiency, Labor	.58	.51	.35	.33	.21
Efficiency, Investment	−.37	−.60	−.85	−.61	−.37
Efficiency, Government Consumption	−.28	−.34	−.36	−.37	−.33
Labor, Investment	−.19	−.20	−.17	−.29	−.36
Labor, Government Consumption	−.12	−.32	−.48	−.54	−.55
Investment, Government Consumption	−.02	−.04	−.13	−.02	.03

[a] Series are first logged and detrended using the HP filter.

Figures 1–4

Examining the U.S. Great Depression
Annually, 1929–39; Normalized to Equal 100 in 1929

Figure 1
U.S. Output and Three Measured Wedges

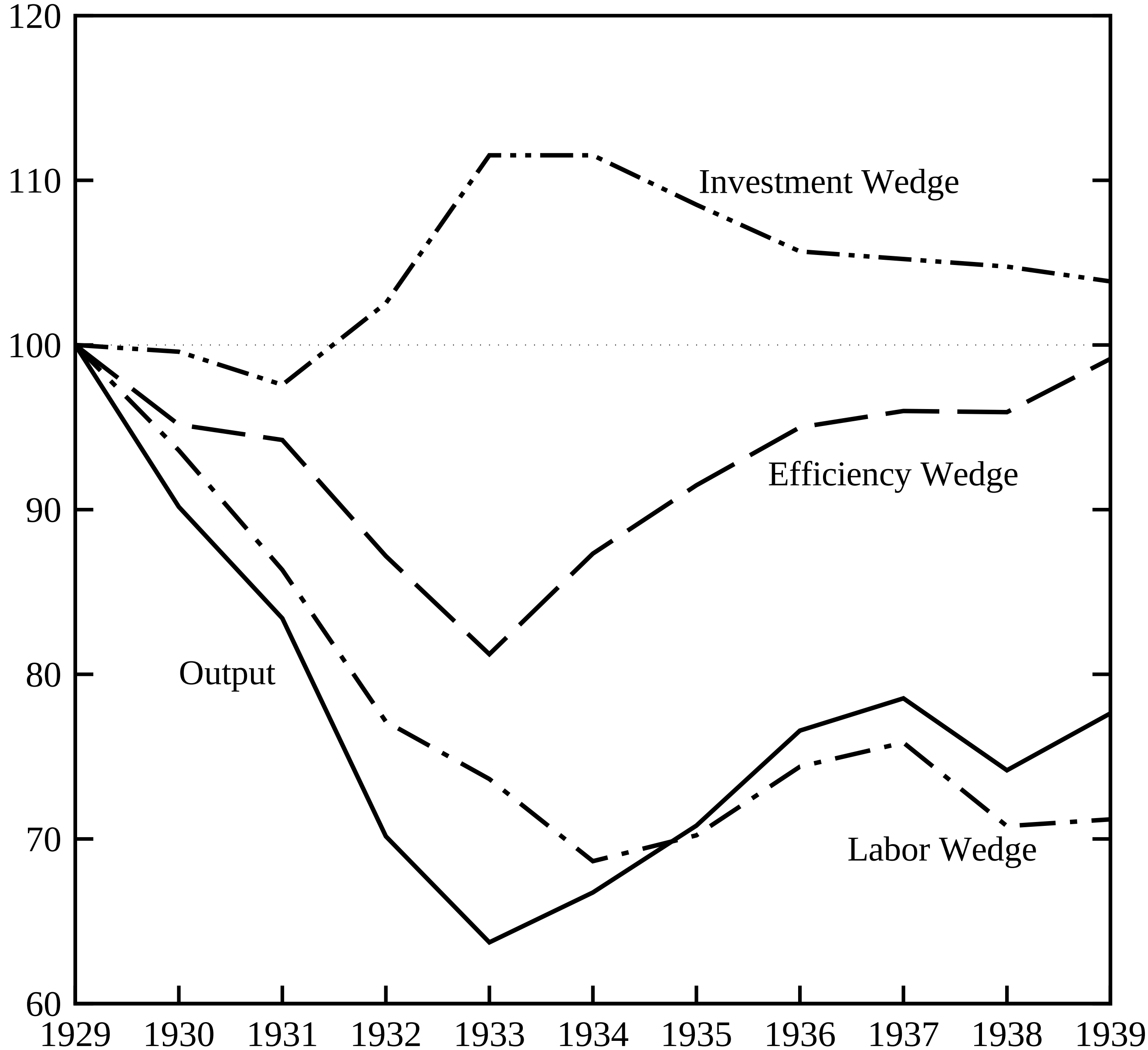


Figure 2
Data and Predictions of the Models With Just One Wedge

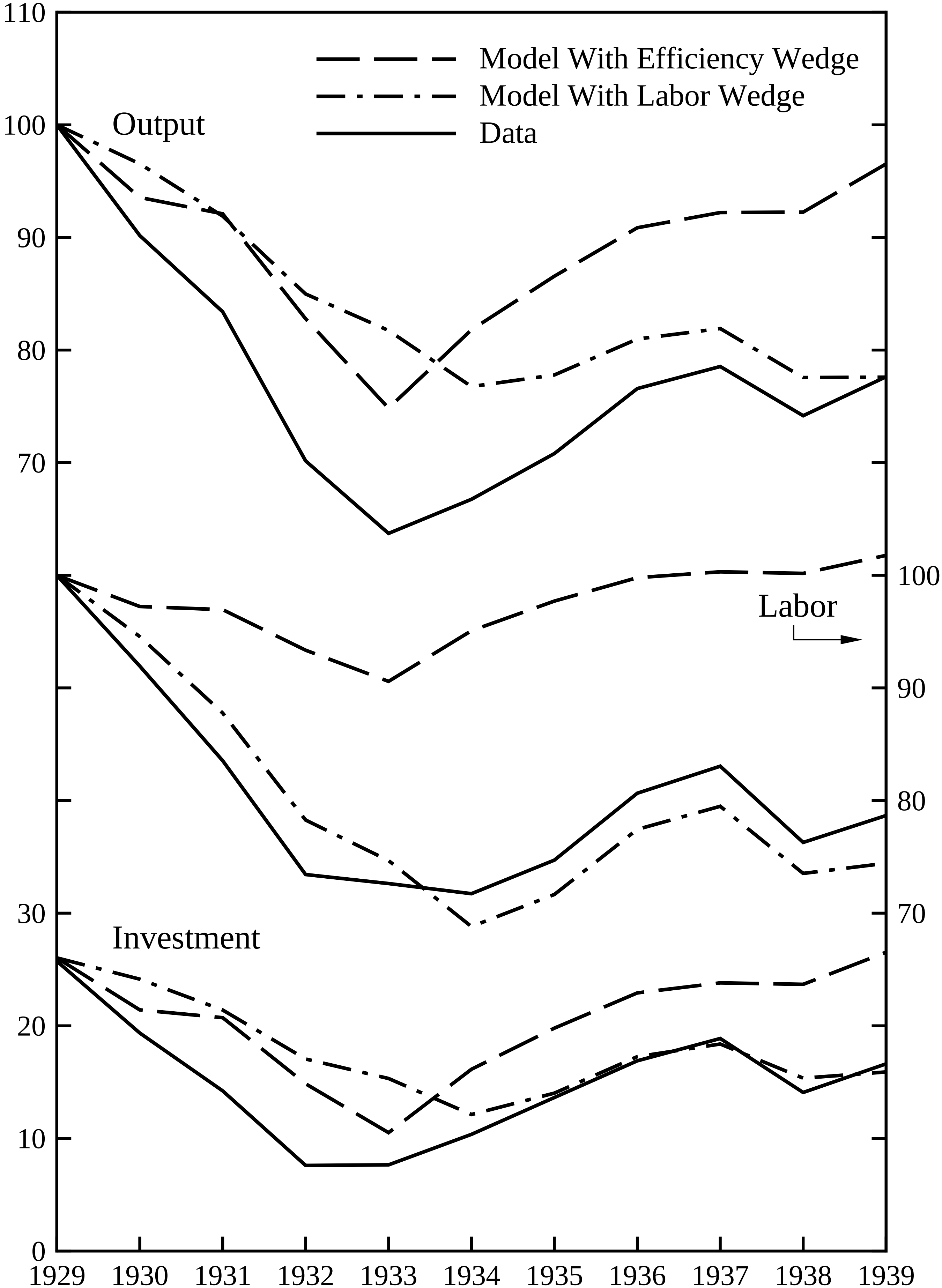


Figure 3
Data and Predictions of the Model With Just the Investment Wedge

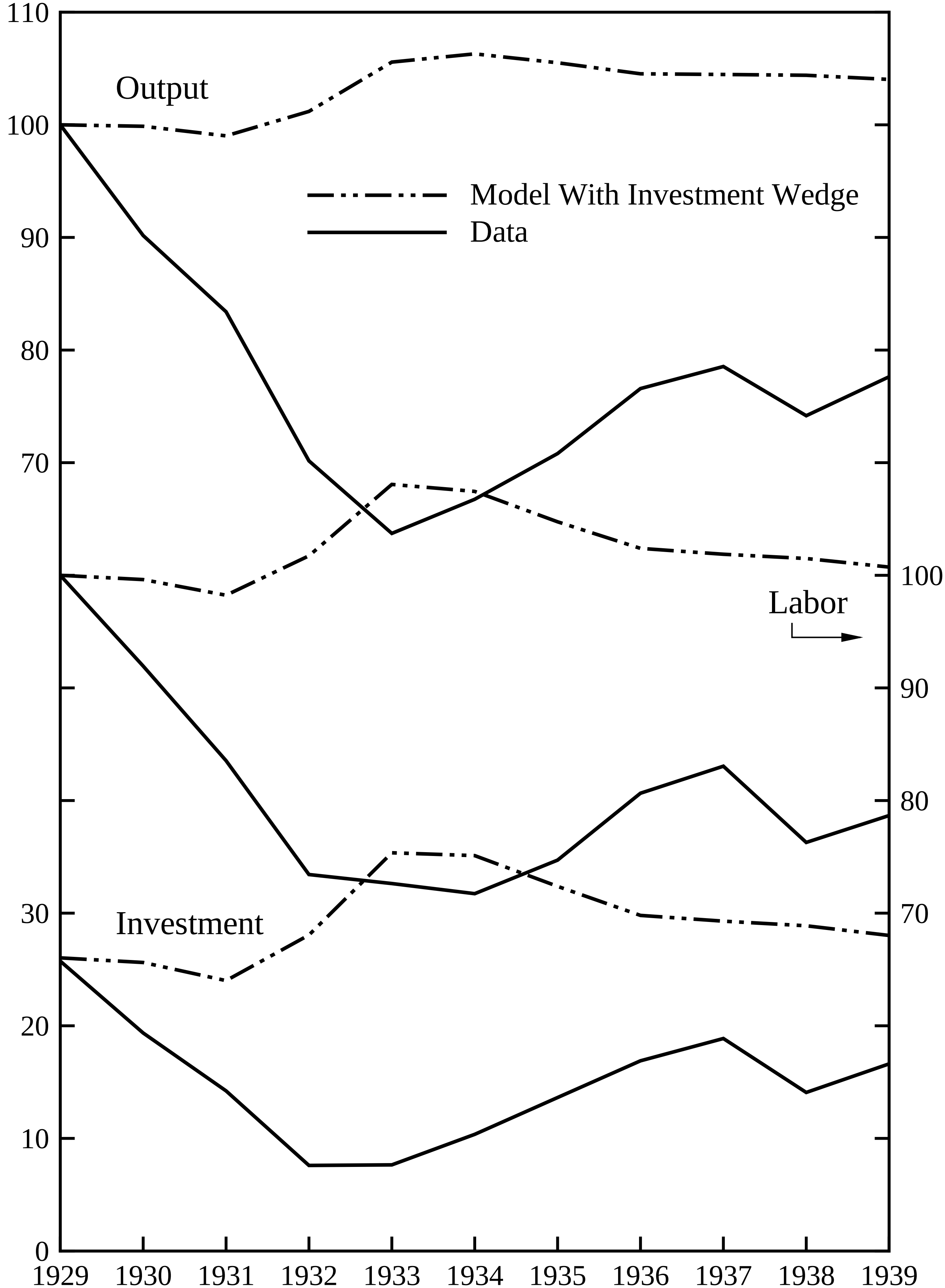
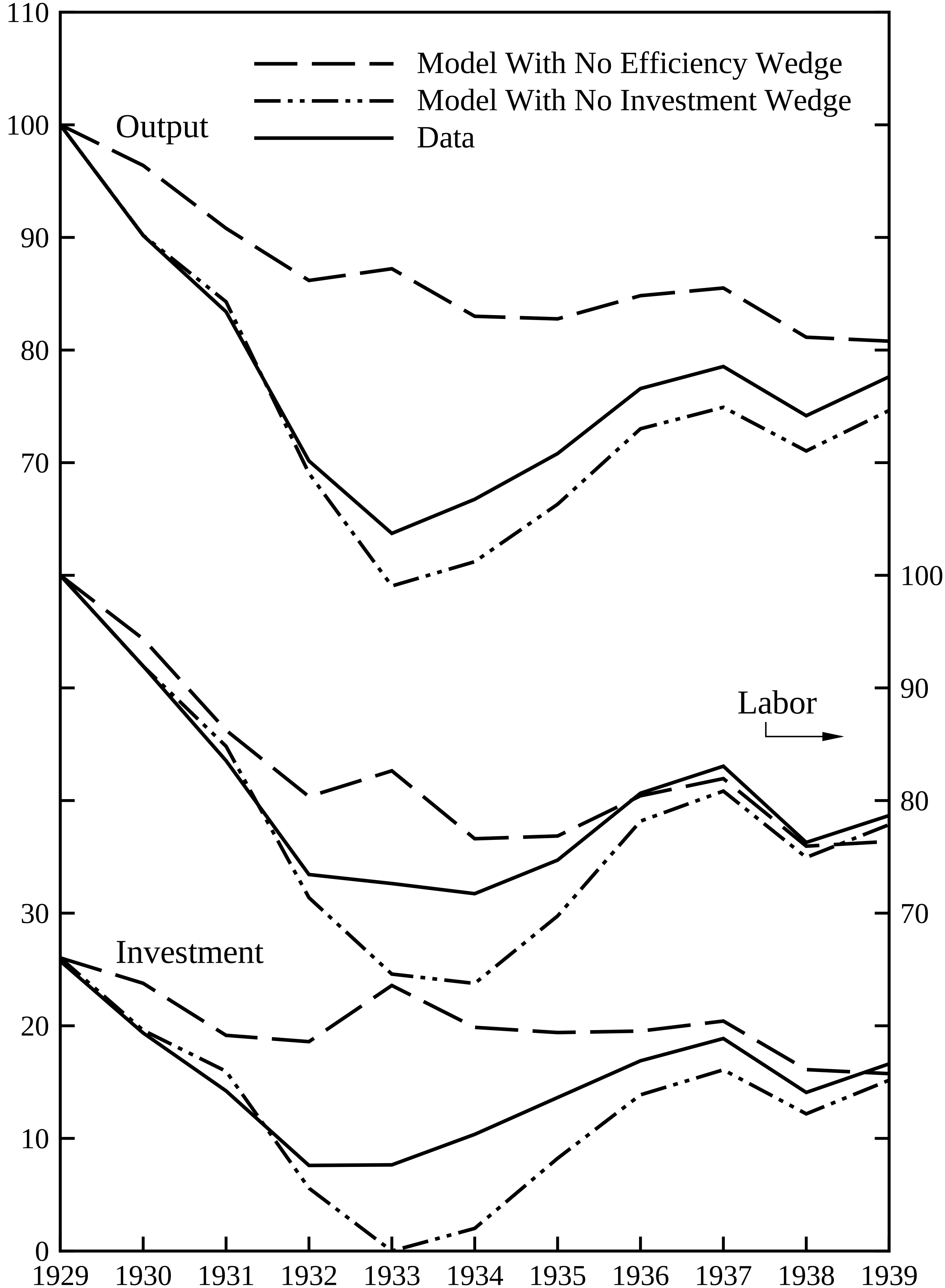


Figure 4
Data and Predictions of the Models With All Wedges But One



Figures 5–8

Examining the 1982 U.S. Recession
Quarterly, 1979:1–1985:4; Normalized to Equal 100 in 1979:1

Figure 5
U.S. Output and Three Measured Wedges

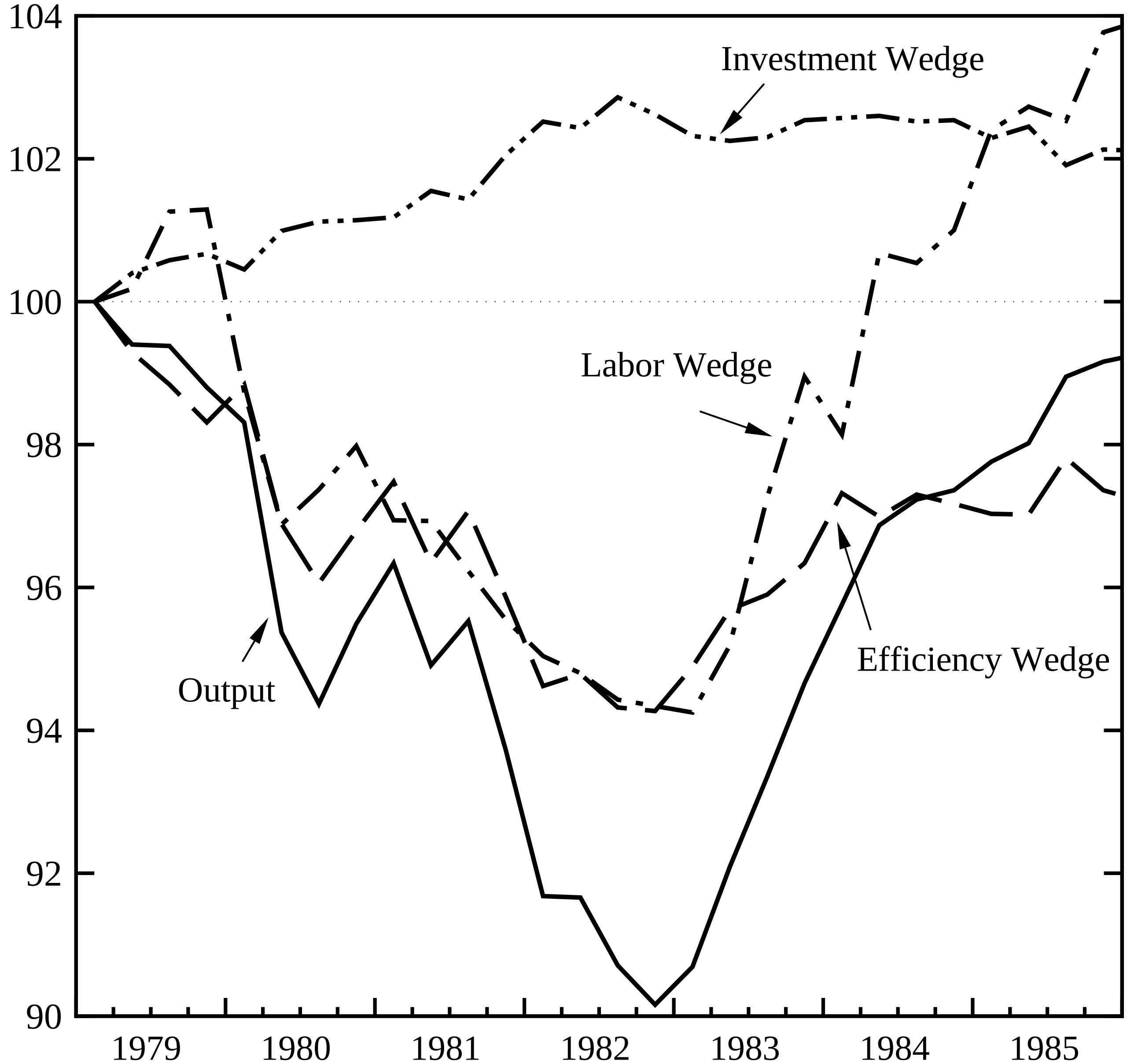


Figure 6
Data and Predictions of the Models with Just One Wedge

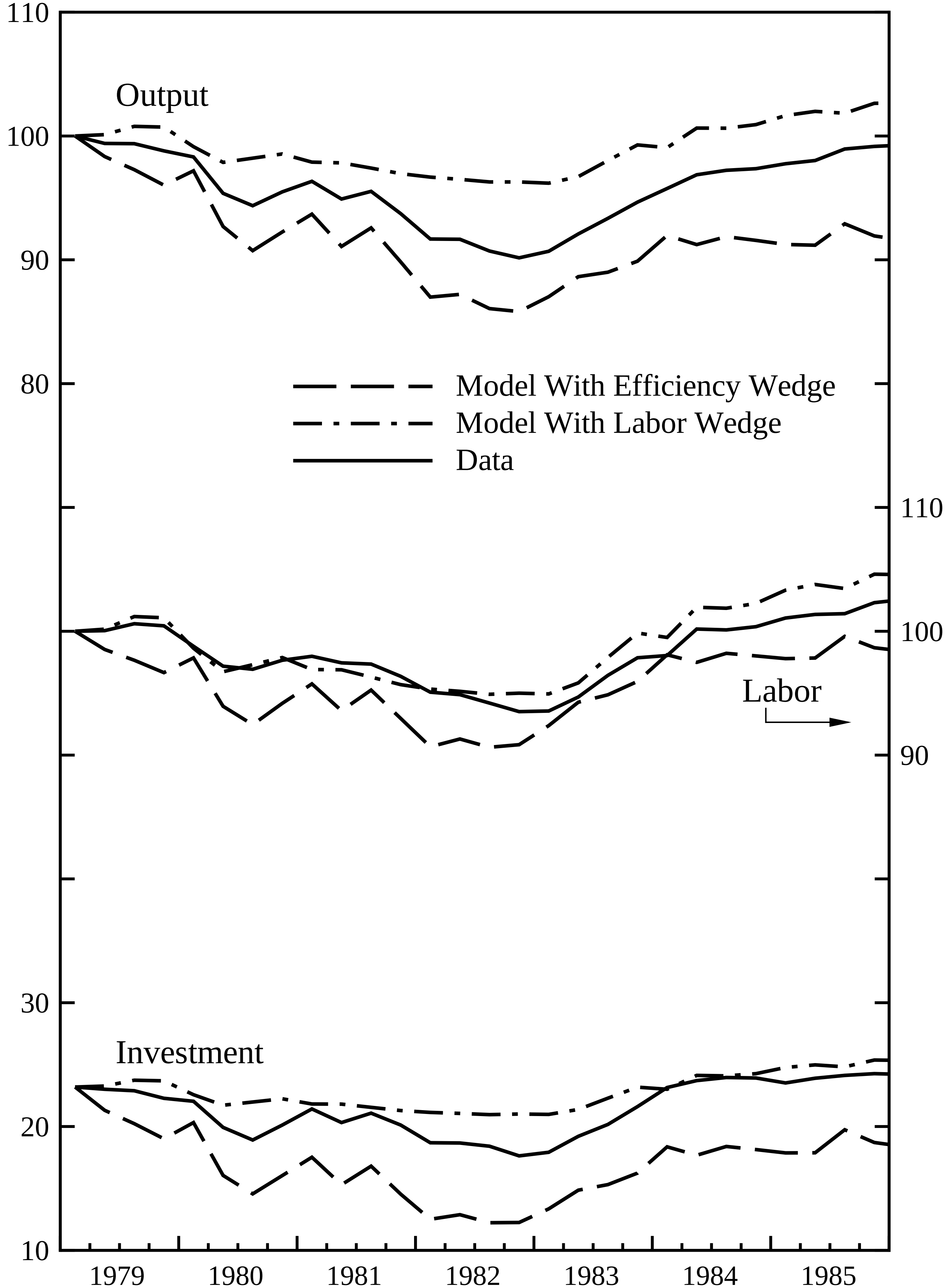


Figure 7
Data and Predictions of the Model With Just the Investment Wedge

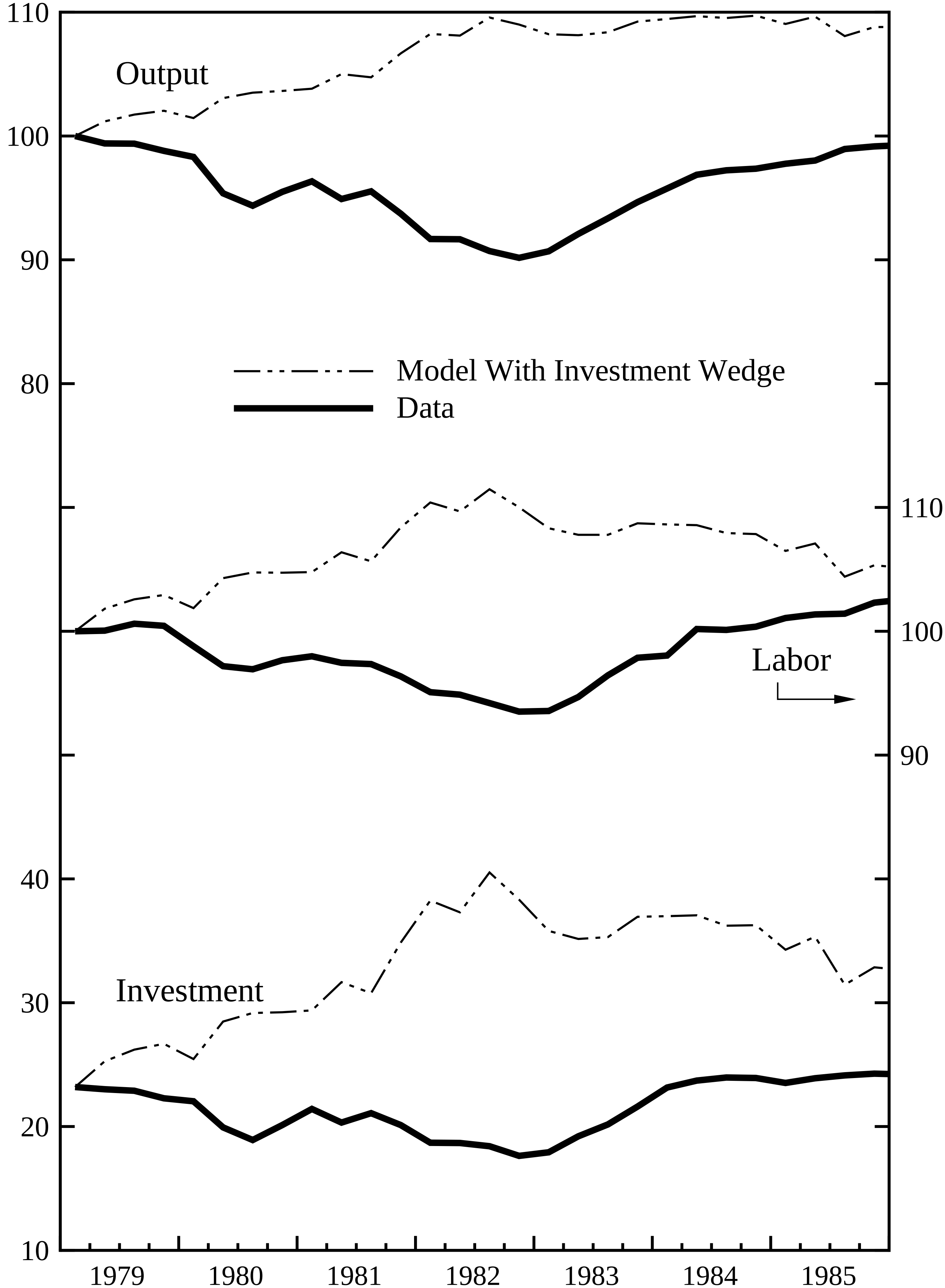
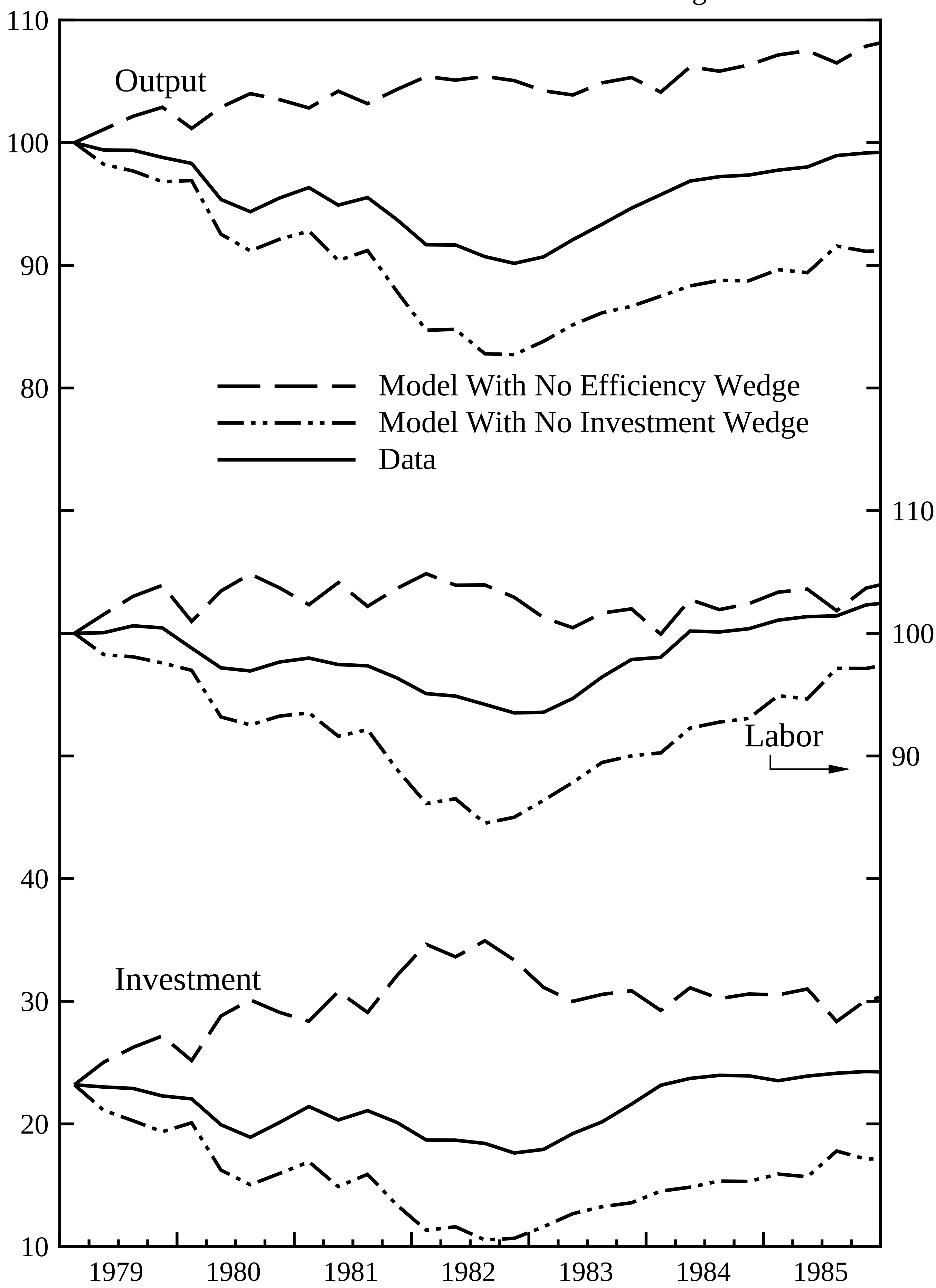


Figure 8
Data and Predictions of the Models With All Wedges But One



Figures 9–12

Varying the Capital Utilization Specification
During the Great Depression Period, 1929–39

Figure 9
Measured Efficiency Wedges for Two Capital Utilization Specifications

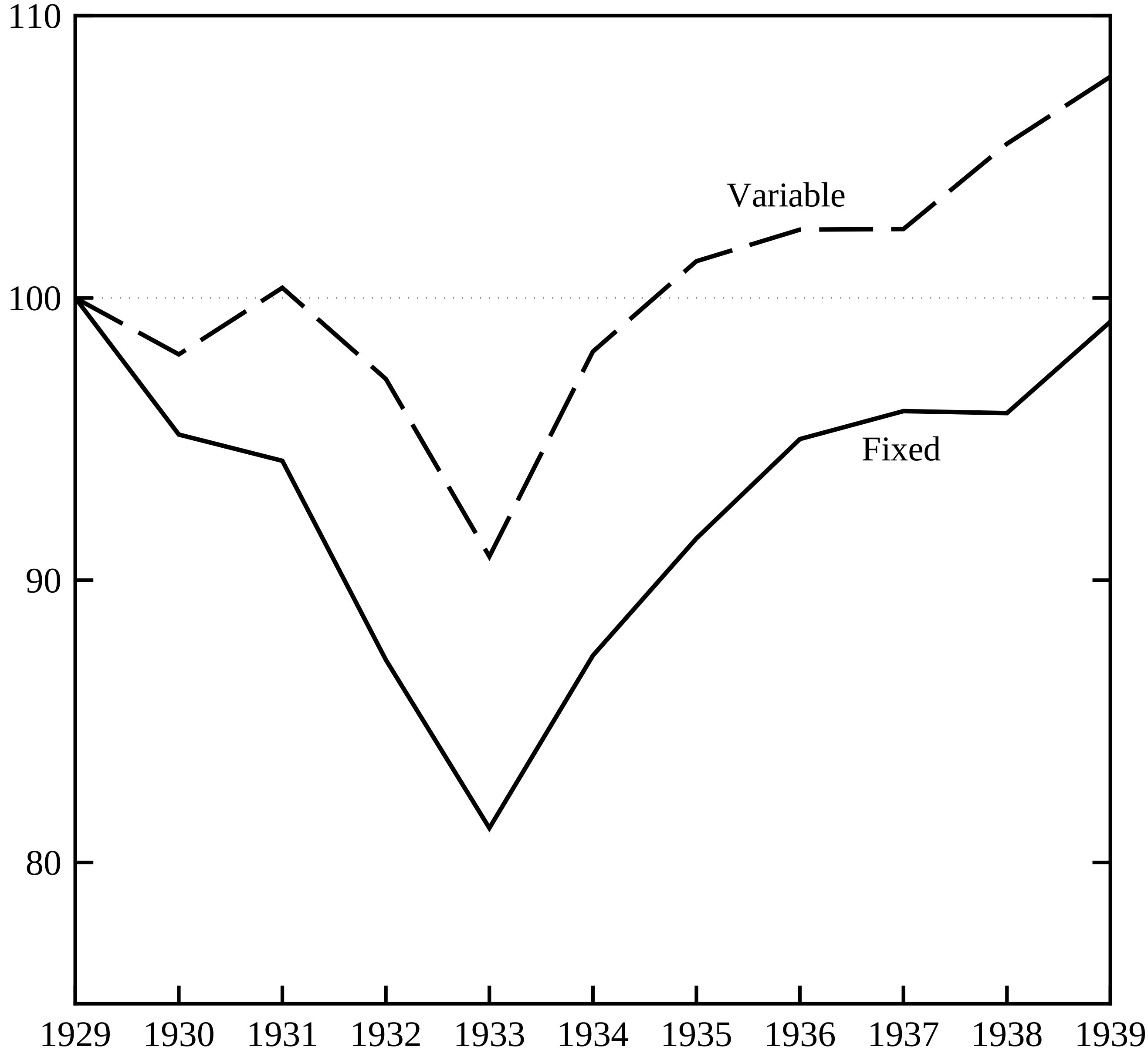


Figure 10
Data and Predictions of the Models With
Variable Capital Utilization and Just One Wedge

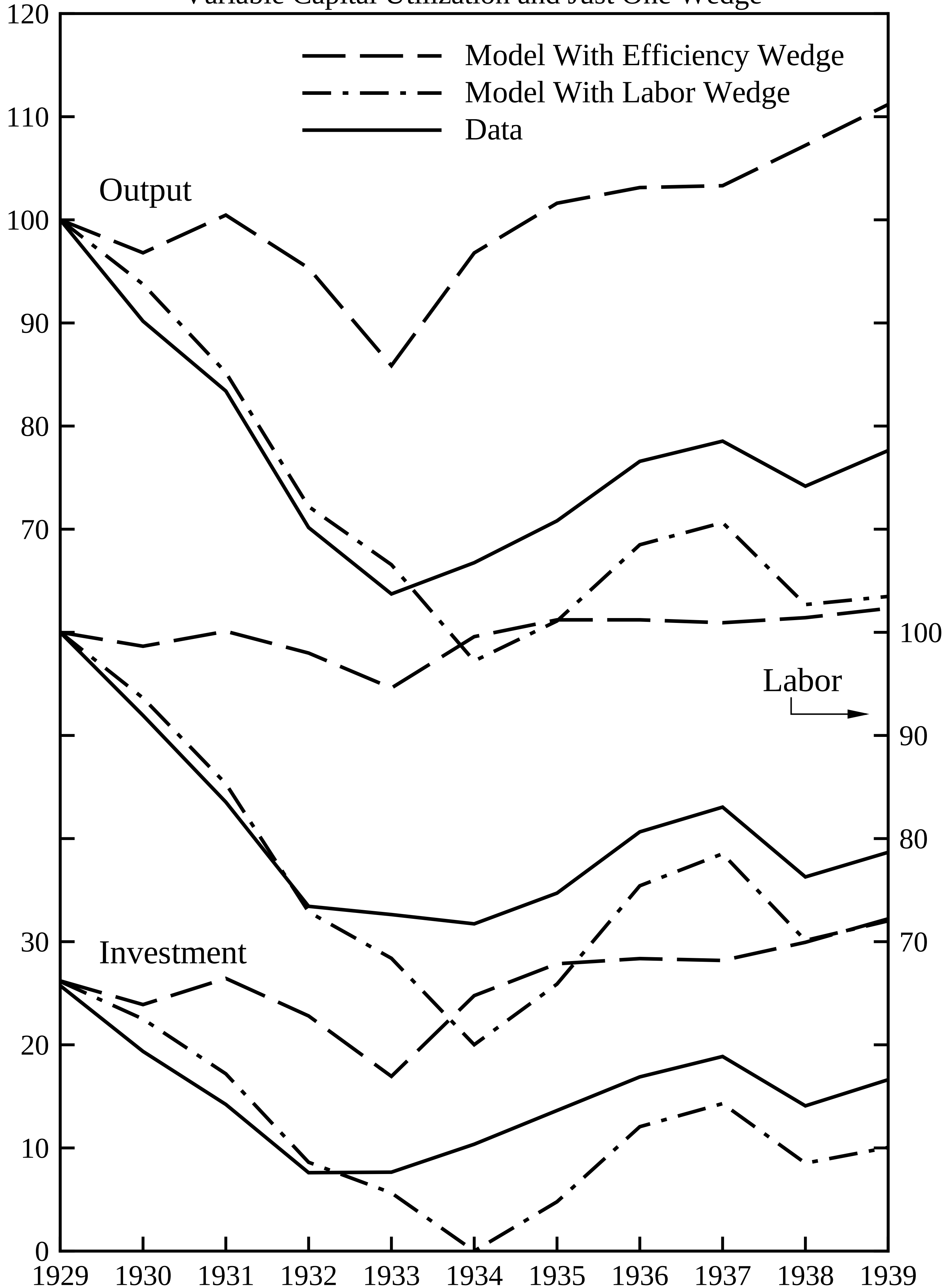


Figure 11
Data and Predictions of the Model With
Variable Capital Utilization and Just the Investment Wedge

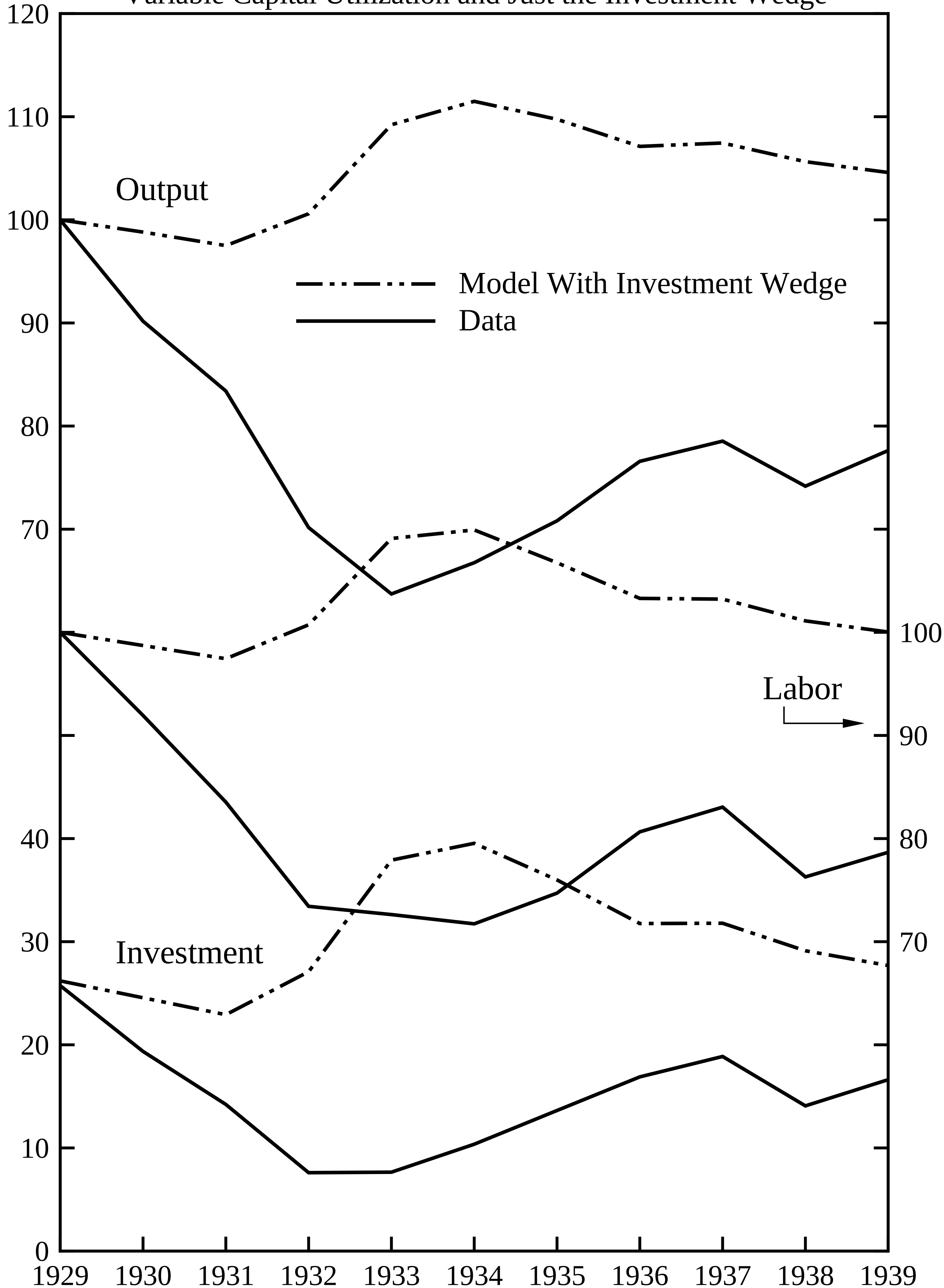
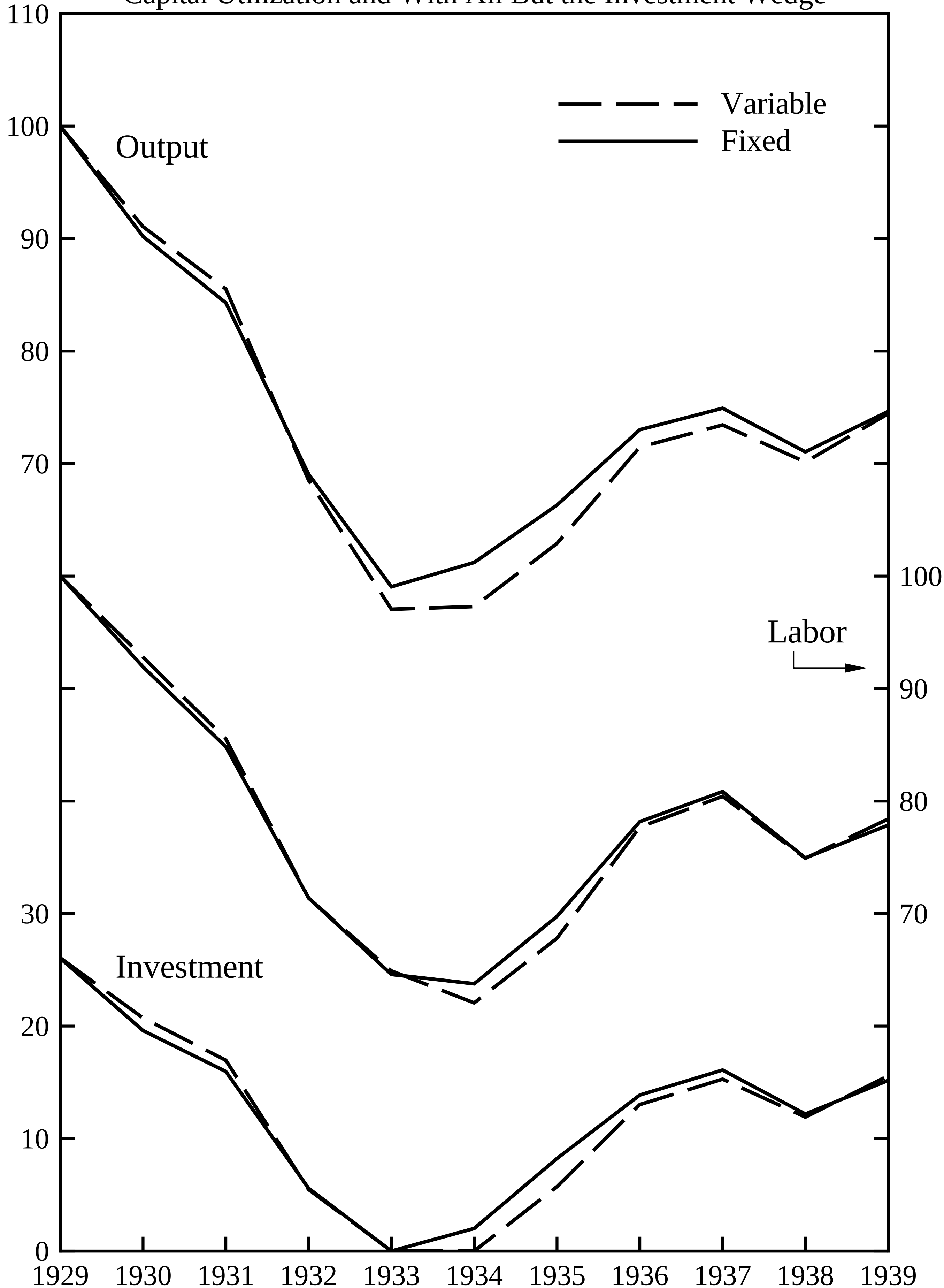


Figure 12
Predictions of the Models with Fixed and Variable
Capital Utilization and With All But the Investment Wedge



Figures 13–14

Varying the Adjustment Cost Specification
During the Great Depression Period, 1929–39

Figure 13
Measured Investment Wedges for Three Adjustment Cost Specifications

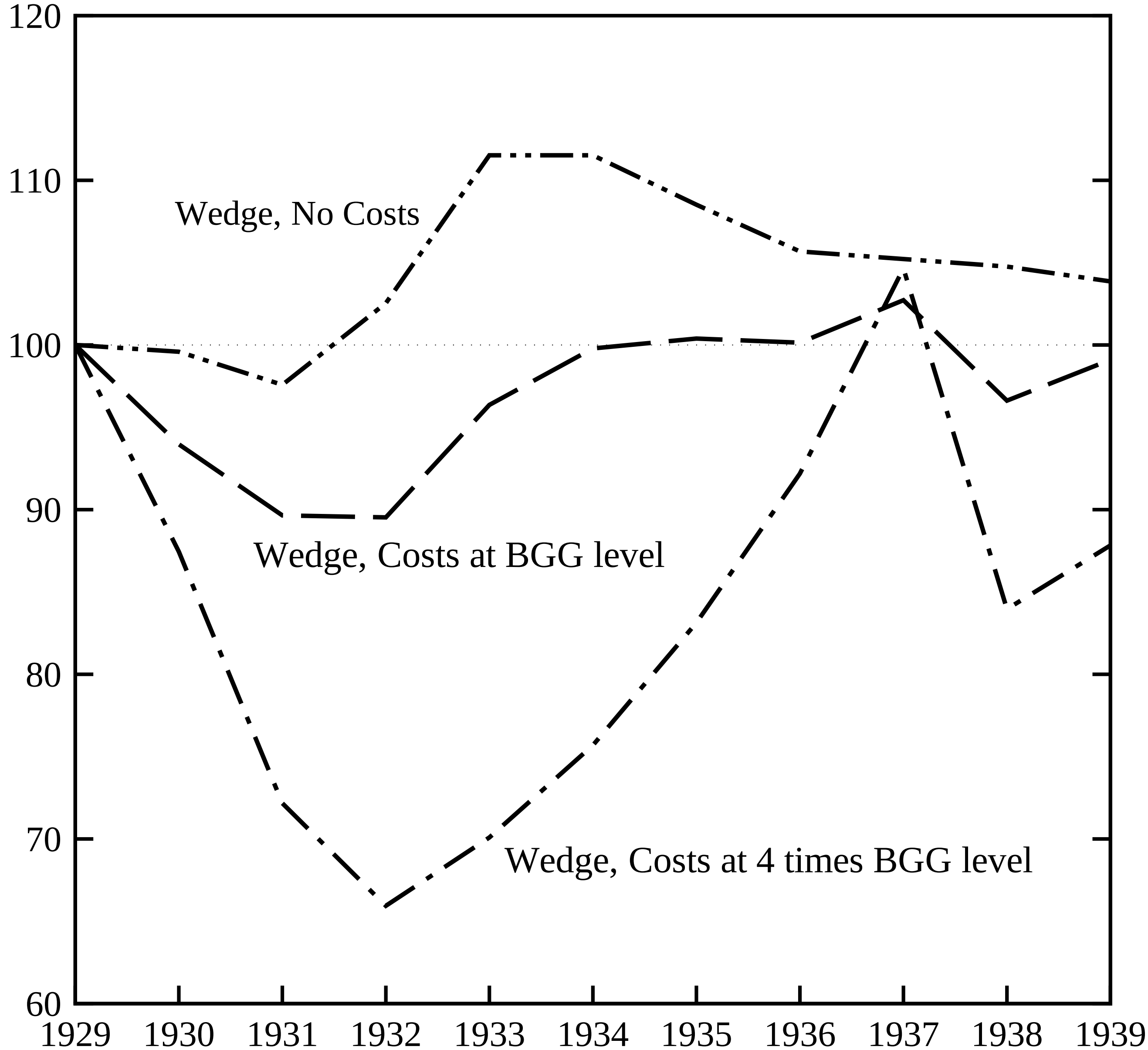


Figure 14
Predictions of the Model With Alternative Adjustment Cost Specifications and Just the Investment Wedge