Monetary Policy in a Low Inflation Economy with Learning*

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In theory, monetary policies that target the price level, as opposed to the inflation rate, should be highly effective at stabilizing the economy and avoiding deflation in the presence of the zero lower bound on nominal interest rates. With such a policy, if the short-term interest rate is constrained at zero and the inflation rate declines below its trend, the public expects that policy will eventually engineer a period of above-trend inflation that restores the price level to its target level. Expectations of future monetary accommodation stimulate output and inflation today, mitigating the effects of the zero bound. The effectiveness of such a policy strategy depends crucially on the alignment of the public's and the central bank's expectations of future policy actions.

This article considers an environment where private agents have imperfect knowledge of the economy and therefore continuously reestimate the forecasting model that they use to form expectations. I find that imperfect knowledge on the part of the public, especially regarding monetary policy, can undermine the effectiveness of price-level targeting strategies that would work well if the public had complete knowledge. For low inflation targets, the zero lower bound can cause a dramatic deterioration in macroeconomic performance with severe recessions occurring with alarming frequency. However, effective communication of the policy strategy that reduces the public's confusion about the future course of monetary policy significantly reduces the stabilization costs associated with the zero bound. Finally, the combination of learning and the zero bound implies the need for a stronger policy response to movements in the price level than would otherwise be optimal. Such a policy is effective at stabilizing both inflation and output in the presence of learning and the zero bound even with a low inflation target.

1. Introduction

The successful reduction of inflation to low levels in many countries raises the question of how to best design monetary and fiscal policies to reduce the risk of deflation and to facilitate a rapid return to price stability if deflation occurs. The experience of deflation and near-zero short-term interest rates in Japan and the brief flirtation with inflation and interest rates around 1 percent in the United States led to a renewal of research into the design of monetary policy that takes account of the zero lower bound on nominal interest rates. A recurring finding in this literature is that monetary policy strategies that explicitly or implicitly target the price level, as opposed to the inflation rate, should be highly effective at both mitigating the effects of the zero lower bound and at minimizing the duration and depth of deflationary episodes (see Reifschneider and Williams 2000, Svensson 2001, and Eggertsson and Woodford 2003). In these models, the promise of future, indeed at times distant future, above-trend inflation aimed at restoring the price level to its target level provides a powerful pull on an economy experiencing deflation and constrained by the zero lower bound. Indeed, according to this research, a central bank can successfully target a constant price level with virtually no cost in terms of macroeconomic stabilization resulting from the zero bound.

These results rely on two crucial assumptions. The first assumption is that the central bank can credibly commit to follow such a price-level targeting policy. Eggertsson (2006) challenges the assumption that the central bank can necessarily commit to future high inflation following a period of deflation associated with monetary policy being constrained by the zero lower bound. If the central bank lacks the ability to commit to future high inflation, the upward pull on in-

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flation and output from the future is diminished as the public rightly anticipates that the central bank will choose only to bring inflation back to its target level and let the fall in the price level be a bygone.

The second critical assumption is that private agents properly anticipate the implications of the monetary policy strategy for the future path of policy and the economy. Reifschneider and Roberts (2006) show that price-level targeting monetary policy rules may lose some of their effectiveness in the presence of the zero bound when expectations are allowed to deviate from rational expectations. In this article, I examine the role of expectations formation on the effectiveness of monetary policy strategies in the presence of the zero bound. I follow the recent literature on learning and consider environments where agents have imperfect knowledge of the structure of the economy and monetary policy strategy and regularly update their beliefs about both based on past experience. I explore the conditions under which imperfect knowledge weakens or even disables the expectations channel that is essential to many proposed monetary policy strategies in the face of the zero lower bound. In addition, I examine the implications for monetary policy design to make it more robust to the presence of both imperfect knowledge and the zero bound.

This article also creates a framework to analyze the effects of communication strategies that help the public predict the future course of monetary policy. A number of papers that propose specific policy actions such as pegging the exchange rate, influencing longer-term bond rates, and increasing the monetary base when the interest rate is already zero highlight the communication aspect of such policy actions (see Meltzer 2001, Svensson 2001, McCallum 2002, Okina and Shiratsuka 2004, and McGough, Rudebusch, and Williams 2005). But these papers typically assume that the public is fully informed about the determination of monetary policy and the behavior of the economy, so the benefits of central bank communication cannot be analyzed directly. Orphanides and Williams (2005a) show that improving the public's understanding of the policy rule reduces errors in private expectations and, in so doing, improves macroeconomic performance. But, this analysis ignores the zero bound. As shown in this article, the presence of the zero bound further complicates the public's learning problem and amplifies the costs associated with expectation errors. Therefore, the benefits of clearly communicating policy are heightened.

This analysis reveals three main findings. First, imperfect knowledge on the part of the public, especially regarding monetary policy, can undermine the effectiveness of monetary policy strategies that would be highly effective if the public had complete knowledge. For low inflation targets, the zero lower bound can engender a dramatic deterioration in macroeconomic performance, with severe recessions occurring relatively frequently. Second, effective communication of the policy strategy that reduces the public's confusion about the future course of monetary policy also significantly reduces the stabilization costs associated with the zero bound. Third, the combination of learning and the zero bound implies the need for a stronger policy response to movements in the price level than would otherwise be optimal. Indeed, such a policy rule is better at stabilizing both inflation and output in the presence of learning and the zero bound, and is highly effective even in the case of an inflation target of only 1 percent.

The remainder of the article is organized as follows. Section 2 describes the model and monetary policy. Section 3 describes the formation of expectations. Section 4 outlines the model simulation methodology and describes the calibration of model parameters. Section 5 reports the results of the monetary policy analysis. Section 6 concludes.

2. The Model

This section describes the empirical macroeconomic model used for this analysis. The model is a so-called hybrid New Keynesian model (see Woodford 2003 for further details and references regarding similar models). The model contains key features of output and inflation dynamics of many recent micro-founded models used for monetary policy evaluation (see, for comparison, Levin et al. 2006). Each period in the model corresponds to one quarter of a year.

2.1. Output and Inflation

The output gap (the deviation of output from its natural rate), denoted by y_t, is given by:

$$(1) \qquad y_t - \eta y_{t-1} = -\phi(i_t - F_{t-1}\pi_{t+1} - r_t^*) - \phi F_{t-1}\{\sum_{j=1}^{\infty}(i_{t+j} - \pi_{t+j+1} - r_{t+j}^*)\}, \; r_t^* \sim N(\bar{r}^n, \sigma_r^2),$$

where F_{t-1} refers to the agents' forecast based on information available at the end of period $t-1$, i_t is the short-term nominal interest rate, π_t is the inflation rate, and r_t^* is the stochastic natural rate of interest (around a fixed long-run value of $\bar{r}^*$, assumed to follow an independently and identically distributed (iid) Gaussian distribution with variance σ_r^2. The lag of the output gap in the equation captures the effects of habit in preferences. Note that because I consider deviations from rational expectations where agents have imperfect knowledge of the true structure of the economy, I replace the standard mathematical expectations with private agents' forecasts. In addition, as emphasized by Preston (2005), under imperfect knowledge one cannot make the substitutions that are commonly used in the literature to rewrite this equation in terms of finite leads of the output gap. Instead, I assume that decisions are based explicitly on expectations of the fundamental determinants of the output decision.

The equation for inflation is based on a Calvo pricing model with partial indexation of prices to lagged inflation:

$$(2)\quad \pi_t - \rho\pi_{t-1} = \kappa(y_t - \theta y_{t-1}) + u_t + F_{t-1}\{\sum_{j=1}^{\infty}\beta^j[\kappa(y_{t+j} - \theta y_{t+j-1}) + u_{t+j}]\}, \quad u_t \sim N(0,\sigma_u^2),$$

where u_t is a markup shock, assumed to follow an iid Gaussian distribution with variance σ_u^2. As in the case of the output equation, pricing decisions are assumed to be based on expectations of their fundamental determinants.

2.2. Monetary Policy

I assume that the central bank's objective is to minimize the weighted sum of the unconditional variances of the inflation gap (the difference between the inflation rate and its target), the output gap, and the short-term nominal interest rate. The central bank loss, $\mathcal{L}$, is given by

$$(3)\qquad \mathcal{L} = \mathrm{VAR}(\pi_t - \pi^*) + \lambda\mathrm{VAR}(y_t) + \nu\mathrm{VAR}(i_t),$$

where $\mathrm{VAR}(x)$ denotes the unconditional variance of a variable x, λ is the relative weight on output gap variability, and ν is the relative weight on nominal interest rate variability. In the following, I assume that $\lambda = 0.5$ and $\nu = 0.1$. This choice of ν assures that the degree of interest rate variability is similar to the historical experience in the United States over the past period of 1985 to 2005.

Based on the findings of the theoretical literature, I assume that monetary policy follows a reaction function that reacts to the gap between the price level and a deterministic trend. I start with the "difference rule" specification of monetary policy similar to that advocated by Orphanides and Williams (2006), given by

$$(4)\qquad i_t = \max\{i_{t-1} + \gamma_\pi(\pi_{t-1} - \pi^*) + \gamma_{\Delta y}\Delta y_{t-1}, 0\},$$

where Δ denotes the first difference operator, and the "max" function reflects the presence of the zero lower bound on nominal interest rates.[1] I assume that the central bank responds to data with a one-quarter lag. Note that by integrating this equation (and assuming the rule is followed without deviation), it is identical to a policy rule where the level of the interest rate is determined by the price level gap (that is, the difference between the price level and a deterministic trend), the level of the output gap, and a constant. Orphanides and Williams (2006) show that rules of this form are robust to uncertainty regarding the model of agents' expectations, be it rational expectations or learning. However, that analysis abstracts from the zero lower bound on interest rates.

As noted by Reifschneider and Williams (2000), the zero lower bound poses a problem for difference rules in that past deviations owing to the zero bound are carried forward into an excessively high current interest rate mechanically through the effects of the lagged interest rate. An alternative implementation that is equivalent in the absence of the zero bound but avoids this problem with the zero bound is for monetary policy to follow the integrated version of the rule:

$$(5)\qquad i_t = \max\{\gamma_\pi(p_{t-1} - p^*_{t-1}) + \gamma_{\Delta y}y_{t-1} + \bar{i}^*, 0\},$$

where p_t is the log of the price level, p^*_t is the target price level that follows $p^*_t = p^*_{t-1} + \pi^*$, and the final term

$$\bar{i}^* = \pi^* + \bar{r}^*$$

is the long-run neutral nominal interest rate.

2.3. Fiscal Policy

Eggertsson and Woodford (2004) show that fiscal policy can be used to complement monetary policy when the zero bound is a constraint on policy. In order to explore the ability of monetary policy alone to cope with the zero bound, this model does not consider the use of government spending or distortionary taxes as a complement to monetary policy. Instead, I assume that in general the fiscal authority is entirely passive. Given this assumption, in periods of severe deflation, the economy can get stuck in a deflationary trap. In such cases, I assume that fiscal policy will take steps that limit the duration of such an episode to five years, at which time the economy is brought back to steady state. From then on, fiscal policy reverts to a passive role. As discussed later, this "backstop" fiscal intervention occurs very rarely when monetary policy is doing a good job of stabilizing the economy on average, and therefore is best viewed as a means of keeping the computation of model moments from being dominated by extreme outliers. Regular occurrences, on the other hand, indicate that the stipulated monetary policy rule does not stabilize the system effectively.

3. Expectations Formation

In the model, agents form expectations using a reduced-form forecasting model of the economy as opposed to using the

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[1] I could impose a slightly positive lower bound of i^{LB}. In terms of the analysis, this corresponds exactly to an inflation target for $\pi^* - i^{LB}$. The experience of Japan over the past decade suggests that the lower bound is very near zero.

full structural model that would be the case under model-consistent (i.e., rational) expectations. I specify the forecasting model such that it exactly corresponds to the reduced form of the structural model under the joint assumptions of rational expectations and the absence of the zero lower bound on nominal interest rates. I assume that agents continuously reestimate the forecasting model based on past observations using a constant-gain least squares algorithm (see Sargent 1993 and Evans and Honkapohja 2001 for a fuller discussion of constant gain learning). Given the structure of the model and the stipulated form of the monetary policy rule, under rational expectations and ignoring the zero bound, five variables—the inflation rate, the output gap and its first lag, the interest rate, and an intercept—fully describe the state of the economy at the end of a period. In the model, agents compute forecasts using a linear forecasting model with these five explanatory variables. At the end of each period, agents reestimate this forecasting model using the currently available data and then use the resulting model to construct forecasts. I also consider alternative assumptions regarding how agents forecast interest rates within the context of their forecasting model.

Let Y_t denote the 1×3 vector consisting of the period t values of the variables to be forecast: $Y_t = (\pi_t, y_t, i_t)$. Let X_t denote the 1×5 vector consisting of the explanatory variables: $X_t = (\pi_{t-1}, y_{t-1}, i_{t-1}, y_{t-2}, 1)$. Estimation is described as follows: Let c_t be the $j \times 5$ vector of coefficients of the forecasting model. Then, using data through period t, the parameters for the constant-gain least squares forecasting model can be written as:

$$c_t = c_{t-1} + \mu R_t^{-1} X_t (X_t - X_t' c_{t-1}), \tag{6}$$

$$R_t = R_{t-1} + \mu (X_t X_t' - R_{t-1}), \tag{7}$$

where $\mu > 0$ is the gain.

In the case of forecasts of the interest rate, I deviate from this simple forecasting method. First, I impose the zero lower bound on forecasts of all future nominal interest rates. Specifically, in period t I compute the forecast for $t+1$ variables. If the forecasted value of the interest rate in period $t+1$ is negative, that value is set to zero. I then compute the $t+2$ forecast of all variables and follow the same procedure, and so on. In this way, the zero bound is enforced both on the actual value of the interest rate and on expectations of future interest rates.[2] In principle, agents need forecasts for infinitely many periods in the future. However, to keep the problem tractable, I approximate this infinite sum with a truncated sum of k periods, replacing the terms for periods $k+1$ and beyond with the period $k+1$ forecast of the appropriate variables, as follows:

$$\begin{aligned} y_t - \eta y_{t-1} = & -\phi (i_t - F_{t-1}\pi_{t+1} - r_t^*) \\ & -\phi F_{t-1}\{\sum_{j=1}^{k} (i_{t+j} - \pi_{t+j+1} - r_{t+j}^*)\} \\ & + F_{t-1}\{y_{t+k+1} - \eta y_{t+k}\}, \end{aligned} \tag{8}$$

$$\begin{aligned} \pi_t - \rho\pi_{t-1} = & \kappa (y_t - \theta y_{t-1}) + u_t \\ & + F_{t-1}\{\sum_{j=1}^{k} \beta^j [\kappa (y_{t+j} - \theta y_{t+j-1}) + u_{t+j}]\} \\ & + \beta^{k+1} F_{t-1}\{\pi_{t+k+1} - \rho\pi_{t+k}\}. \end{aligned} \tag{9}$$

Given the dynamics of the system, $k = 20$ is sufficient to get accurate solutions, and I use that value for all results reported here. The results with $k = 40$ are generally very close to those for $k = 20$.

I consider two alternative ways for agents to form forecasts of the interest rate. The first approach is simply to use the model as described above. Absent the zero bound, the interest rate equation in the forecast model is identical to that describing policy, so the fit of the forecasting equation is perfect. The presence of the zero bound, however, introduces positive deviations from the simple linear policy rule. The basic forecasting model implicitly treats these deviations as part of the interest rate process, and these deviations affect the forecast of future interest rates directly through the lagged interest rate in the model, and indirectly through the effect on the estimated parameters of the interest rate equation in the forecasting model.

The second approach to modeling agents' interest rate forecasts is for agents to use the actual policy rule in forming forecasts, conditional on the forecasts of inflation and the output gap. This is accomplished by substituting the policy rule for the interest rate equation in the forecasting model. In particular, if the nominal interest rate depends on the lagged price level and output gap, then agents will not be fooled by deviations from the rules and will forecast monetary policy to eventually restore the price level to its target.

4. Model Solution and Calibration

This section describes the method used to compute model statistics and the calibration of the model parameters. Owing to the presence of the zero lower bound and learning, the standard methods of solving and computing unconditional moments of linear rational expectations models do not apply. Instead, I use simulated moments as approximations of the unconditional moments.

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[2] Note that this method implicitly imposes certainty equivalence by ignoring the distribution of interest rate forecasts and its effect on the expected interest rate from the zero bound. Incorporating this channel requires the use of computationally intensive nonlinear methods and is beyond the scope of this article.

4.1. Model Simulation Methodology

For a given parameterization of the model, the simulated model moments are computed based on a single stochastic simulation consisting of 101,000 periods, where the first 1000 observations are dropped in order to remove the effects of initial conditions.[3] The initial conditions for all model variables and the forecasting model matrices c and R are given by the corresponding steady-state values of the rational expectations equilibrium with no zero bound. The shocks are generated using MATLAB's Gaussian pseudo-random number generator "randn."

The presence of either the zero bound or learning introduces a nonlinearity into the model that can generate explosive behavior in a simulation of 100,000 periods, even for policy rules that are stable under rational expectations. One potential source of instability under learning is the possibility that the forecasting model itself may become unstable. To mitigate the possibility that instability in the forecasting model generates explosive behavior in the model economy, I do the following. During each period of the simulation, I compute the root of maximum modulus of the forecasting VAR excluding the constants. If the modulus of this root falls below the critical value of 1.1, the coefficients of the forecast model are updated as described earlier; if not, I assume that the forecast model is not updated and the matrices c_t and R_t are held at their respective previous period values. This cutoff is invoked only extremely rarely in the simulations.

However, stability of the forecasting model is not sufficient to assure stability of the full model in all situations. For this reason, I impose a second condition that restrains explosive behavior. In particular, if the absolute values of the inflation gap, output gap, or interest rate gap (the nominal interest rate less the long-run neutral rate), exceed very large values, then the offending variables are simply set to the relevant boundary value. I use a bound of 20 percentage points for the interest rate and the output gap and 10 percentage points for the inflation rate. The upper bounds are included for symmetry. Of course, this lower bound on the nominal interest rate is irrelevant given the zero lower bound that is part of the determination of the interest rate. These bounds are set wide enough that they bind only very rarely or never when policy is effective at stabilizing the economy, but bind more frequently when policy is ineffective, as discussed later.

4.2. Model Calibration

The model simulations consider a range of values of the constant-gain learning parameter, μ. One extreme assumption considered is where the public does not change its estimates at all, but rather uses the parameters associated with the rational expectations equilibrium ignoring the zero bound. Given the presence of the zero bound, the case of $\mu = 0$ is not the same as rational expectations, but is closely related in that the parameters of the forecasting model are constant. As such, it provides a benchmark that replicates key features of outcomes under full model-consistent expectations.

For the case of learning, I use 0.02 as the benchmark value of μ, and consider alternative values of 0.01 and 0.03 as a robustness exercise. A number of researchers have estimated the value of μ within a learning framework using postwar U.S. data (see Sheridan 2003, Milani 2007 and 2008, Orphanides and Williams 2005b, and Branch and Evans 2006). Although the estimates differ across specifications and samples, and are in some cases quite imprecise, the central tendency of these estimates is between 0.02 and 0.03. The value of 0.02 implies that the data from the past 10 years account for a little more than one-half of the weight in the estimation, data from the preceding 10 years account for one-quarter of the weight, and data more than 20 years old account for the remaining weight. The average age of the data used in estimation is about 12.5 years, the same as would be the case if agents used standard least squares regressions with 25 years of data. This seems a plausible value given the data limitations that people face in the real world.

I calibrate the model parameters describing the output gap and inflation dynamics using Milani's (2008) estimates of a very similar model under learning.[4] The upper part of Table 1 reports these parameter values. Note that they are fixed across the different specifications of the learning rate.

The calibration of the long-run neutral real interest rate is important in terms of interpreting the results with respect to the optimal choice of an inflation target. The neutral long-run nominal interest rate, $\bar{i}^*$, measures the average "cushion" that the central bank has in lowering rates, starting from the deterministic steady state. The larger the cushion, that is, the larger is $\bar{i}_t$, the less frequently the zero lower bound constrains policy and the shorter the periods during which the constraint is binding. In terms of this analysis, the decom-

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[3] Based on simulations under rational expectations in which I can compute the moments directly, this sample size is sufficient to yield very accurate estimates of the unconditional variances. In addition, testing indicates that 1000 periods is sufficient to remove the effects of initial conditions on simulated second moments.

[4] Milani (2008) estimates a model where the shocks to the natural rate of interest and the markup follow AR(1) processes. This model is quite similar to the one used in this article, once one applies the appropriate transformation to eliminate the serial correlation to the shocks. Therefore, Milani's estimates are reasonable for the model used in this article. Moreover, the parameter estimates are within the range of other estimates of similar models in the literature.

Table 1
Model Calibration

Parameter	Calibrated values			
φ	0.200			
η	0.945			
β	0.990			
κ	0.078			
ρ	0.849			
θ	0.849			
μ	0.000	0.010	0.020	0.030
σ_r	7.500	7.500	7.250	6.750
σ_u	0.550	0.539	0.528	0.507

Notes: Parameter values reported in the upper part of the table are taken from Milani (2006), Table 3.3. The calibration of the values of the long-run neutral real interest rate, $\bar{r}^*$, and the innovation standard deviations are described in the text.

position of the long-run neutral nominal interest rate into its real and inflation components is irrelevant. However, to aid in the interpretation, it is useful to discuss the results in terms of the inflation target as opposed to the neutral nominal rate. For this purpose, I assume that the long-run real neutral rate is 2.5 percent, near its long-run average in the postwar U.S. economy.[5] Thus, in the following, results for the case of an inflation target of x percent refer to an economy with a neutral long-run nominal interest rate of $x + 2.5$ percent.

The innovation variances are crucial for conducting analysis with the zero bound on interest rates. All else equal, the larger the variances, the more often the zero bound constrains policy and the larger are the effects of the zero bound. I therefore take pains to calibrate these variances in a manner consistent with the empirical evidence on the U.S. economy over 1985–2005. First, I compute the variances of the GDP price index inflation rate and the federal funds rate over the sample of 1985–2005. I then choose the innovation variances so that the model-generated unconditional variances assuming rational expectations and no zero bound are close to their respective empirical counterparts for the federal funds rate and the inflation rate. (I assume no covariance in the innovations.) This method yields the values of the calibrated standard deviations of the innovations, which are reported in the first column of the lower part of the table.

As noted by Orphanides and Williams (2005a), the presence of learning tends to raise the magnitude of fluctuations in a model economy relative to that which occurs under rational expectations. This is also true for the model analyzed in this article. Therefore, in order to make the models with the different values of μ comparable in terms of baseline unconditional moments before introducing the zero bound, I calibrate the innovation variances separately for each value of μ, so that the model-generated unconditional variances of inflation, the output gap, and the short-term interest rate are about the same in all variants of the model.[6] The innovation variances decline slightly as the value of μ rises.

5. Monetary Policy Evaluation

In this section, I analyze the performance of monetary policy rules in environments where the zero lower bound is occasionally binding under alternative assumptions regarding the formation of expectations.

5.1. Benchmark Monetary Policy Rule

I start by constructing a benchmark monetary policy rule. For this purpose, I use the methods described in Levin, Wieland, and Williams (1999) to compute the coefficient values for γ_π and $\gamma_{\Delta y}$ in the monetary policy rule that minimizes the central bank loss assuming rational expectations and abstracting from the zero lower bound. The resulting coefficient values are given by $\gamma_\pi = 0.1$ and $\gamma_{\Delta y} = 1$. Orphanides and Williams (2005a, 2006) show that optimal policy under learning responds more strongly to inflation than under rational expectations, so I also consider a more aggressive variant of the rule with $\gamma_\pi = 0.25$. I consider two versions of the policy rule, the "difference rule" given by equation (4) and the explicit price-level targeting rule given by equation (5). As noted earlier, these rules are identical in the absence of the zero bound but differ in an economy where the zero bound is occasionally binding.

5.2. The Effects of the Zero Bound without Learning

I first consider the case where the public does not reestimate its forecasting model, that is, $\mu = 0$. I assume that the parameters of the forecast model are those implied under rational expectations and the absence of the zero lower bound. This might be a reasonable assumption if the zero bound had not been a constraint on policy in the past.

As expected, the "difference" specification of the policy rule fares very poorly with low inflation targets. The upper part of Table 2 shows the results under the difference rule. For these experiments, I assume that the public uses the benchmark forecasting model. For inflation targets of 1.5 percent and above, the zero bound has little effect and the economy

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[5] This calculation is based on using the personal consumption deflator as the price measure. This is the same value for $\bar{r}^*$ used by Reifschneider and Williams (2000). For alternative assumptions regarding this value of $\bar{r}^*$, one can translate the results in the following section by modifying the assumed values of π^* so that the underlying values of $\bar{i}^*$ are the same.

[6] For this calibration exercise, I use a policy rule of $\gamma_\pi = 0.25$ and $\gamma_{\Delta y} = 1$.

Table 2
The Effects of the Zero Bound without Learning ($\mu = 0$)
Baseline Policy Rule: $\gamma_\pi = 0.1$, $\gamma_{\Delta y} = 1$

	Root mean square				Frequency	
Inflation target (π^*)	Inflation	Output gap	Interest rate	Central bank loss	$i_t = 0$	$y_t \leq -20$
Policy follows difference rule (equation 4), and public forecasts with same						
0.0	3.7	7.5	1.8	28.0	22.8	12.0
0.5	2.2	4.5	1.8	10.1	10.2	3.4
1.0	1.2	2.6	1.8	3.4	3.7	0.4
1.5	0.9	2.0	1.8	2.2	1.5	0.0
2.0	0.9	2.0	1.8	2.1	0.7	0.0
3.0	0.9	1.9	1.8	2.0	0.1	0.0
4.0	0.9	1.9	1.8	2.0	0.0	0.0
Policy follows price level rule (equation 5), but public forecasts with difference rule						
0.0	1.5	3.1	1.7	4.9	12.3	1.3
0.5	1.0	2.2	1.8	2.5	6.4	0.2
1.0	0.9	2.0	1.8	2.1	3.2	0.0
1.5	0.9	2.0	1.8	2.0	1.6	0.0
2.0	0.9	1.9	1.8	2.0	0.7	0.0
3.0	0.9	1.9	1.8	2.0	0.1	0.0
4.0	0.9	1.9	1.8	2.0	0.0	0.0
Policy follows price level rule (equation 5), and public forecasts with same						
0.0	0.9	1.9	1.7	2.0	8.2	0.0
0.5	0.9	1.9	1.7	2.0	4.9	0.0
1.0	0.9	1.9	1.8	2.0	2.7	0.0
1.5	0.9	1.9	1.8	2.0	1.4	0.0
2.0	0.9	1.9	1.8	2.0	0.7	0.0
3.0	0.9	1.9	1.8	2.0	0.1	0.0
4.0	0.9	1.9	1.8	2.0	0.0	0.0

never experiences severe recessions, as indicated by the percent of the time that the output gap is below –20 percent. But, for inflation targets of 1 percent and lower, the zero bound causes a significant deterioration in macroeconomic performance as measured by the simulated root mean squared values of the inflation rate and the output gap. For an inflation target of zero, this policy rule no longer effectively stabilizes the economy and severe recessions are a regular occurrence.

The problem with the difference rule as specified in equation (4) is that it implicitly allows upward drift in the price-level target when the zero bound is constraining policy, or is expected to constrain policy in the future. Thus, by including the lagged interest rate in the rule, this policy undermines the price-level targeting feature that is crucial for success in the face of the zero bound. For this reason, the remainder of the article focuses on rules that explicitly target the price level, in the form of equation (5).

The middle panel of the table shows the results for the explicit price-level targeting policy rule, where the public uses the benchmark forecasting model. This policy does a better job than the difference rule with low inflation targets. For inflation targets of 1 percent and above, the zero bound has little effect on macroeconomic performance. However, for inflation targets below 1 percent, the zero bound causes a marked rise in the average magnitude of fluctuations.

This deterioration in performance occurs because agents do not understand that the central bank will eventually bring the price level back to its target value. Instead, they implicitly assume that following periods when the zero bound is constraining policy, the central bank will let bygones be bygones and will act to stabilize the inflation rate, irrespective of the realized price level. For example, assume that the current interest rate is zero and policy is constrained. Agents forecast the future path of interest rates conditional on the current level of interest rates. As a result, interest rate forecasts will be higher than implied by the monetary policy rule, which accounts for the price level. As a result, the expectations channel—which is so powerful and helpful when the public understands the central bank is intent on restoring the price level to its target—is distorted and macroeconomic stabilization suffers.

If the public understands that the central bank is targeting the price level and incorporates this information in its forecasting model, then the zero bound has no discernible effects on macroeconomic performance even with an inflation target of zero percent. The lower part of Table 2 reports the results. Although this framework does not encompass fully model-consistent expectations, these results where the public knows the policy rule mimic those in the literature where the zero bound is not a problem under price-level targeting (see, for example, Reifschneider and Williams 2000 for comparison).

5.3. The Effects of the Zero Bound with Learning

The presence of learning exacerbates the effects of the zero bound on the economy. The upper part of Table 3 reports the simulation results assuming policy follows the explicit price-level targeting rule but the public uses the benchmark forecasting model with $\mu = 0.02$. The losses associated with the zero bound are much larger than in the case of no learning. Indeed, under these conditions, this policy rule does not effectively stabilize the economy for inflation targets below 2 percent. The zero bound introduces persistent deviations from agents' forecasting models, just as in the case of no learning discussed earlier. But, with learning, there is a second channel by which the zero bound affects expectations. During a prolonged episode in which the zero bound is constraining policy, the behavior of monetary policy and the economy systematically deviate from that implied by the forecasting model. These deviations set in motion movements in the estimated parameters of the forecasting model.

Removing public uncertainty about monetary policy significantly reduces the costs associated with the zero bound under learning. The lower part of Table 3 reports the results where the public's forecasts incorporate knowledge of the monetary policy rule. However, even with full public knowledge of the policy rule, the effects of the zero bound interact with the learning involved with the other equations of the model. As a result, inflation targets below 1 percent carry significant costs in terms of stabilization. Therefore, in the face of imperfect knowledge and the zero bound, more than communication of policy intentions is needed. The parameters of the policy rule need to be modified as well, as shown in the next subsection.

5.4. More Aggressive Monetary Policy

A more aggressive policy rule response to inflation is more effective at minimizing the deleterious effects of the zero lower bound. Table 4 shows the results for the economy with learning where policy follows the more aggressive version of the rule with $\gamma_\pi = 0.25$. The more aggressive rule is effective because it reduces the likelihood of deflation and therefore entering a liquidity trap and it promises prompt and aggressive action once the zero bound is no longer constraining policy.

Assuming the public understands the rule, there is little cost to zero inflation under this rule. Comparing these results to those in the previous table, this rule delivers better stabi-

TABLE 3
THE EFFECTS OF THE ZERO BOUND WITH LEARNING ($\mu = 0.02$)
BASELINE POLICY RULE: $\gamma_\pi = 0.1$, $\gamma_{\Delta y} = 1$

	Root mean square				Frequency	
Inflation target (π^*)	Inflation	Output gap	Interest rate	Central bank loss	$i_t = 0$	$y_t \leq -20$
Policy follows price level rule (equation 5), but public forecasts with difference rule						
0.0	6.7	13.3	3.3	89.8	50.7	40.6
0.5	4.7	9.4	2.9	45.3	27.1	19.5
1.0	3.3	6.6	2.6	22.8	13.4	9.2
1.5	2.5	5.1	2.3	13.4	7.1	5.0
2.0	2.0	4.0	2.2	8.6	3.8	2.8
3.0	1.4	2.9	2.0	4.3	1.2	0.9
4.0	1.0	2.3	1.9	2.7	0.3	0.2
Policy follows price level rule (equation 5), and public forecasts with same						
0.0	1.7	3.8	1.9	6.8	12.3	2.1
0.5	1.5	3.3	2.0	5.2	7.3	1.3
1.0	1.2	2.8	1.9	3.9	4.2	0.8
1.5	1.1	2.5	1.9	3.0	2.2	0.3
2.0	1.0	2.3	1.9	2.8	1.3	0.3
3.0	1.0	2.1	1.9	2.3	0.3	0.1
4.0	0.9	2.1	1.9	2.3	0.2	0.0

lization of both inflation and output at a zero percent inflation target than does the baseline rule with a 1 percent inflation target. Figures 1 and 2 show the distributions of the inflation rate and the output gap, respectively, under the benchmark and more aggressive rules when the inflation target is zero. For these figures, the public forms expectations using the true monetary policy rule. For the inflation rate, I summed the observations below 5 percent into the leftmost bar (and likewise summed the inflation rates above 5 percent into the rightmost bar). For the output gap, I summed the observations that are greater than 10 percent in absolute value. Without learning, given the stipulated objective function, this rule stabilizes inflation too much at the cost of more variability in the output gap. However, with learning, its better containment of inflation helps anchor inflation expectations and avoids deflation and the associated severe recessions.

5.5. Robustness to Alternative Learning Rates

The qualitative results are the same for other values of the learning rate, μ, but quantitatively the losses with low inflation are much larger when the learning rate is 0.03. Tables 5 and 6 show the results for the economy with alternative learning speeds of $\mu = 0.01$ and $\mu = 0.03$, respectively, where policy follows the more aggressive version of the rule with $\gamma_\pi = 0.25$. For the case of $\mu = 0.03$, if the public knows the policy rule, the costs associated with the zero bound rise for inflation targets below 1 percent.

6. Conclusion

The historical experiences of deflation with interest rates constrained at zero in the United States in the 1930s and more recently in Japan suggest that it may be prudent to avoid such situations. One solution is to target an inflation rate a few percentage points above zero. Indeed, for this reason and others, inflation-targeting central banks tend to target an inflation rate around 2 percent. Theoretical research on monetary policy yields a far more optimistic view on the ability of monetary policy to stabilize the economy even with an inflation target of zero. This article suggests a note of caution regarding the effectiveness of monetary policy in the presence of the zero bound if one abandons the assumption that the public has perfect knowledge of the economy and the monetary policy strategy. In a world with imperfect knowledge, policies that would work well if expectations were rational can perform very poorly if the public has imperfect knowledge, especially when the public is uncertain of the policy strategy itself. Although not studied in this article, a clear corollary of the potential difficulty in stabilizing the economy in the presence of the zero bound is the potential use of fiscal policy interventions when policy is constrained at zero, and the need for more research in this area.

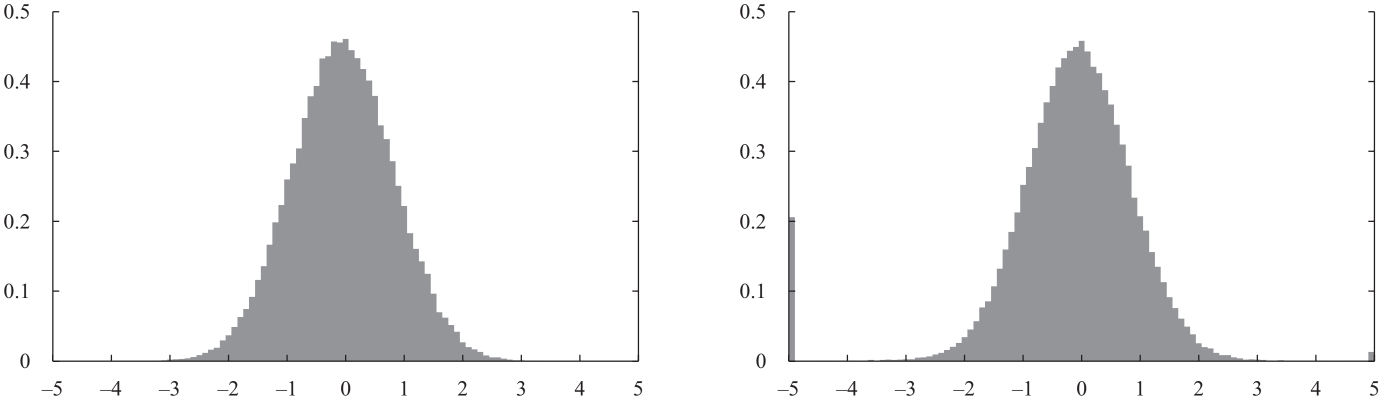
The message of the article is not, however, entirely negative. First, I show that effective communication of the monetary policy strategy can reduce the costs associated with the zero bound. In this respect, the results relate to Eggerts-

(text continues on page 12)

TABLE 4
THE EFFECTS OF THE ZERO BOUND WITH LEARNING ($\mu = 0.02$)
MORE AGGRESSIVE POLICY RULE: $\gamma_\pi = 0.25$, $\gamma_{\Delta y} = 1$

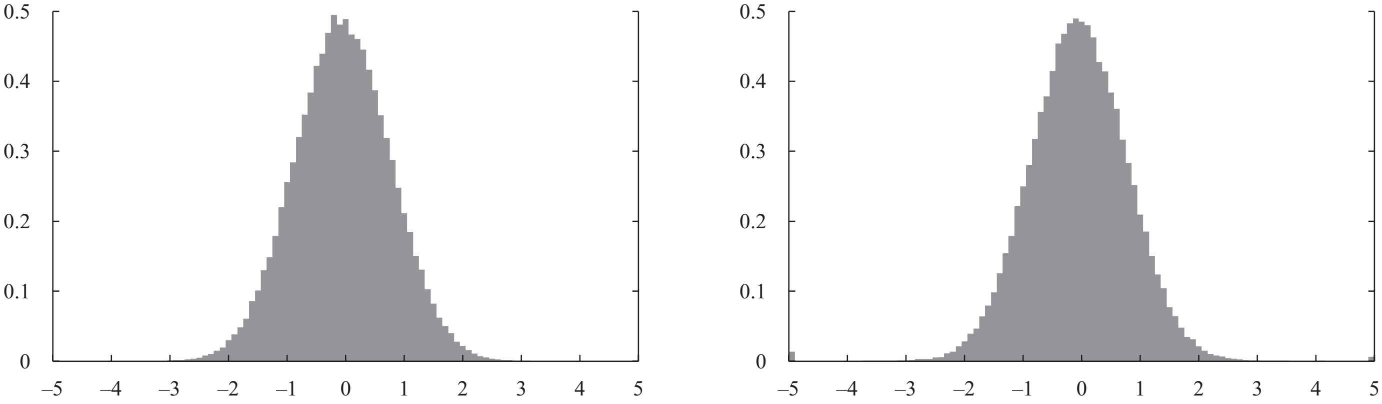
	Root mean square				Frequency	
Inflation target (π^*)	Inflation	Output gap	Interest rate	Central bank loss	$i_t = 0$	$y_t \leq -20$
Policy follows price level rule (equation 5), but public forecasts with difference rule						
0.0	2.0	4.4	1.9	9.2	15.9	3.0
0.5	1.5	3.4	1.9	5.3	8.4	1.3
1.0	1.2	2.8	1.9	3.7	4.5	0.6
1.5	1.0	2.5	1.9	2.9	2.3	0.3
2.0	0.9	2.3	1.9	2.4	1.0	0.1
3.0	0.9	2.2	1.9	2.3	0.2	0.0
4.0	0.8	2.2	1.9	2.3	0.1	0.0
Policy follows price level rule (equation 5), and public forecasts with same						
0.0	0.9	2.7	1.8	3.0	10.8	0.2
0.5	0.9	2.5	1.9	2.6	6.2	0.1
1.0	0.8	2.3	1.9	2.4	3.4	0.0
1.5	0.8	2.3	1.9	2.4	1.8	0.0
2.0	0.8	2.3	1.9	2.4	0.9	0.0
3.0	0.8	2.3	1.9	2.4	0.3	0.0
4.0	0.8	2.2	1.9	2.3	0.1	0.0

FIGURE 1
DISTRIBUTIONS OF INFLATION RATE WITH A ZERO INFLATION TARGET



A. Benchmark policy without learning ($\mu = 0$)

B. Benchmark policy with learning ($\mu = 0.02$)



C. Aggressive policy without learning ($\mu = 0$)

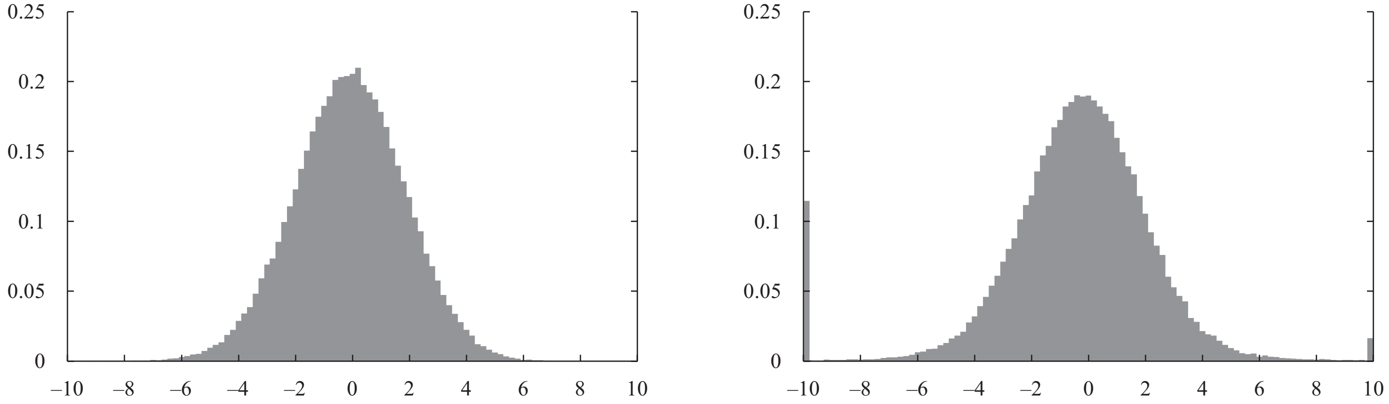
D. Aggressive policy with learning ($\mu = 0.02$)

TABLE 5
THE EFFECTS OF THE ZERO BOUND WITH SLOWER LEARNING ($\mu = 0.01$)
MORE AGGRESSIVE POLICY RULE: $\gamma_\pi = 0.25$, $\gamma_{\Delta y} = 1$

	Root mean square				Frequency	
Inflation target (π^*)	Inflation	Output gap	Interest rate	Central bank loss	$i_t = 0$	$y_t \leq -20$
Policy follows price level rule (equation 5), but public forecasts with difference rule						
0.0	1.2	2.9	1.8	3.9	13.0	0.6
0.5	1.0	2.6	1.8	3.1	7.2	0.3
1.0	0.9	2.3	1.8	2.4	3.7	0.0
1.5	0.8	2.2	1.9	2.3	1.9	0.0
2.0	0.8	2.2	1.9	2.2	0.9	0.0
3.0	0.8	2.2	1.9	2.2	0.2	0.0
4.0	0.8	2.2	1.9	2.2	0.0	0.0
Policy follows price level rule (equation 5), and public forecasts with same						
0.0	0.8	2.3	1.7	2.3	10.2	0.0
0.5	0.8	2.2	1.8	2.2	6.0	0.0
1.0	0.8	2.2	1.8	2.2	3.2	0.0
1.5	0.8	2.2	1.8	2.2	1.7	0.0
2.0	0.8	2.2	1.9	2.2	0.9	0.0
3.0	0.8	2.2	1.9	2.2	0.2	0.0
4.0	0.8	2.2	1.9	2.2	0.0	0.0

FIGURE 2
DISTRIBUTIONS OF THE OUTPUT GAP WITH A ZERO INFLATION TARGET

A. Benchmark policy without learning ($\mu = 0$) **B. Benchmark policy with learning ($\mu = 0.02$)**



C. Aggressive policy without learning ($\mu = 0$) **D. Aggressive policy with learning ($\mu = 0.02$)**

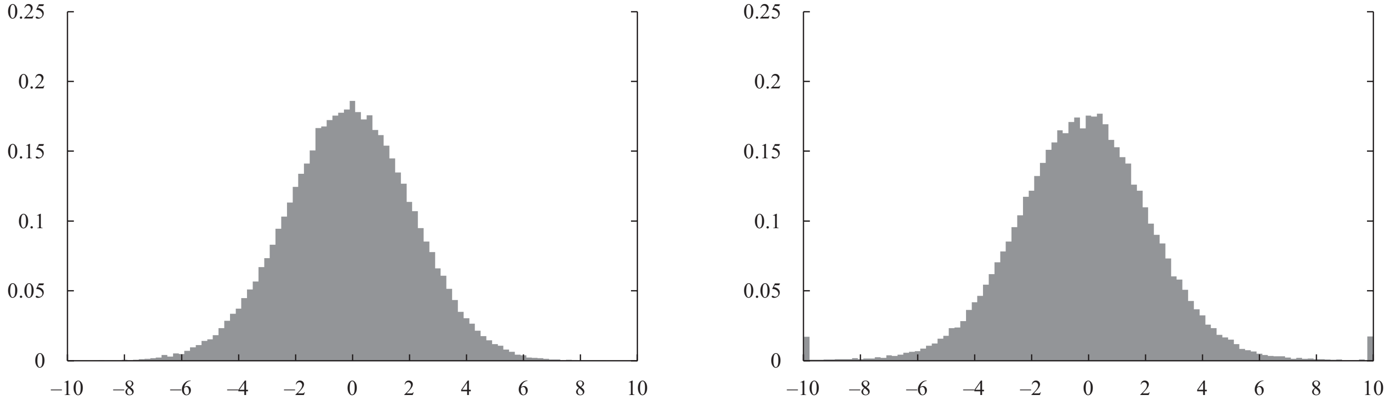


TABLE 6
THE EFFECTS OF THE ZERO BOUND WITH FASTER LEARNING ($\mu = 0.03$)
MORE AGGRESSIVE POLICY RULE: $\gamma_\pi = 0.25$, $\gamma_{\Delta y} = 1$

	Root mean square				Frequency	
Inflation target (π^*)	Inflation	Output gap	Interest rate	Central bank loss	$i_t = 0$	$y_t \leq -20$
Policy follows price level rule (equation 5), but public forecasts with difference rule						
0.0	3.8	8.1	2.5	31.3	24.7	13.6
0.5	2.4	5.3	2.2	13.1	11.4	5.0
1.0	1.7	3.9	2.0	7.0	5.5	2.2
1.5	1.4	3.3	1.9	5.1	3.1	1.3
2.0	1.2	2.9	1.9	4.0	1.7	0.8
3.0	1.0	2.6	1.9	3.1	0.7	0.4
4.0	0.9	2.4	1.9	2.6	0.3	0.2
Policy follows price level rule (equation 5), and public forecasts with same						
0.0	1.2	3.4	2.0	4.8	11.1	0.9
0.5	1.1	3.0	2.0	3.9	6.5	0.5
1.0	1.0	2.7	1.9	3.2	3.5	0.3
1.5	0.9	2.5	1.9	2.7	1.9	0.1
2.0	0.9	2.5	1.9	2.7	1.1	0.1
3.0	0.9	2.4	1.9	2.5	0.5	0.1
4.0	0.8	2.3	1.9	2.4	0.2	0.0

son's (2008) analysis of the effectiveness of the sudden regime shifts in monetary and fiscal policies in 1933 in the United States. Second, I find that a robust strategy to cope with both imperfect knowledge and the zero bound is to respond more strongly to inflation than would be optimal under rational expectations. This policy rule, assuming it is communicated effectively to the public, is highly effective at stabilizing inflation and output even with an inflation target of 1 percent.

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State Business Taxes and Investment: State-by-State Simulations*

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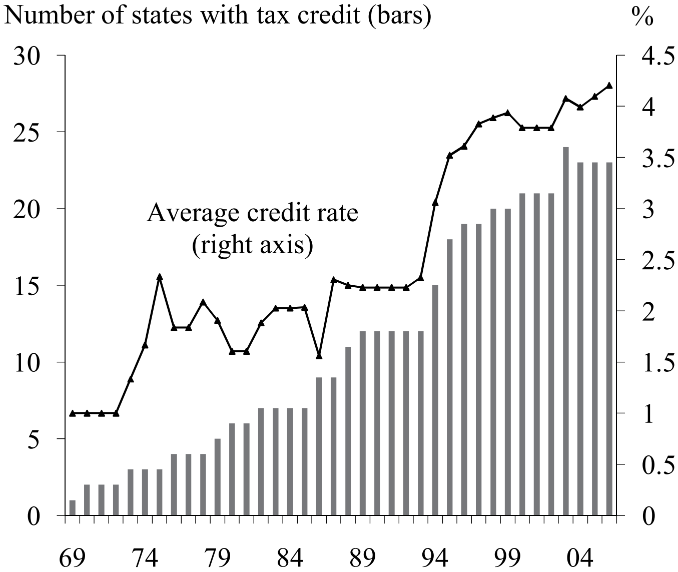
This article develops a framework for simulating the effects of state business taxes on state investment and output. Our simulations provide the predicted increase in investment—both in equipment and structures (E&S) and in research and development (R&D)—and the predicted increase in output for a given state resulting from a specified change in one of its three tax policies—the E&S investment tax credit, the R&D tax credit, or the corporate income tax. The simulations depend on a set of formulas linking economic parameters and state data to investment and output, all of which are reported in this article. We report results, based on our preferred set of parameters, for each of the 48 contiguous states. We also discuss alternative parameter values and explore the resulting sensitivity of predicted changes in state investment and output. Finally, we describe a simple web tool that we have made available online (www.frbsf.org/csip/taxapp.php) that allows users to insert their own preferred parameter values and simulate the economic effects for the state and tax policy of their choosing.

1. Introduction

Business tax incentives have become a powerful weapon in states' fiscal arsenals in recent years. Tax incentives have been used both for countering recessions in the short run and fostering sustainable economic growth in the long run. For example, California's initial budget for fiscal year 2009 passed in February 2009 expanded business tax incentives by $1 billion, even while the state cut spending by $20 billion and hiked personal taxes and fees.[1]

State tax policy has become much more business-friendly in recent years. The first broad, statewide tax credit for investment in equipment and structures (E&S) was enacted in 1969 by New York. By 2006, 23 states offered similar credits and the average credit rate among those states had grown to over four percentage points (see Figure 1). Similarly, state tax credits for investment in research and development (R&D) have become increasingly common and generous since the first such state credit was enacted in 1982 by Minnesota. By

Figure 1
State Investment Tax Credits for Equipment and Structures (E&S), 1969 to 2006



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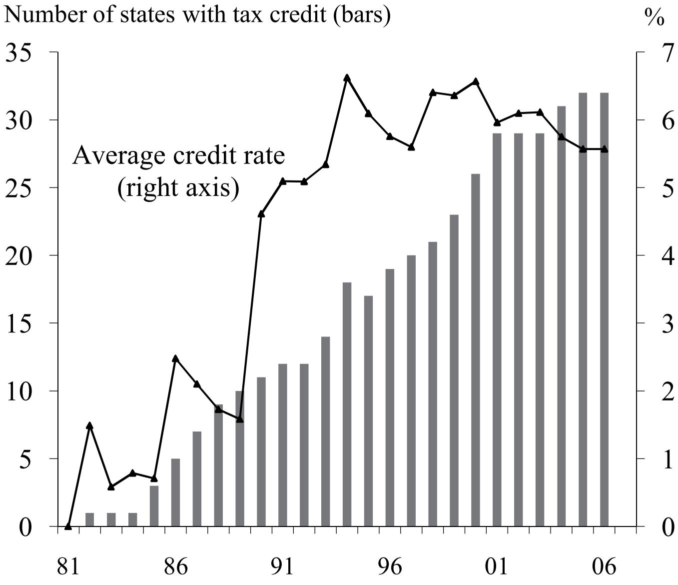
*We thank Robert Tannenwald for suggesting that we translate our research on state taxation and capital formation into the simulation analysis contained in this article. We also thank Ted Wiles for excellent research assistance and Judy Feria for her programming assistance on the web applet described in this article. Financial support from the Federal Reserve Bank of San Francisco is gratefully acknowledged by the first author. All errors and omissions remain the sole responsibility of the authors and the conclusions do not necessarily reflect the views of the organizations with which they are associated.

[1] These tax incentives were later rescinded because continued deterioration in state receipts and the failure of certain ballot initiatives led to a further imbalance in the budget.

Figure 2
State Research and Development (R&D) Tax Credits in the United States, 1981 to 2006



2006, 32 states had an R&D tax credit, and the average rate among those states was 5.5 percentage points (see Figure 2). The proliferation of tax credits in subsequent years, combined with aggressive tax planning vis-à-vis apportionment formulas and passive investment companies, has led to a general decrease in average corporate tax collections over the past 25 years.[2] In response to recently slumping economies, states have accelerated their use of business tax incentives (Silver-Greenberg 2009). Whether such incentives are good public policy is a matter of great debate and controversy. Nonetheless, it is clear that states' reliance on such incentives have increased tremendously over the past few decades.

What impacts should state policymakers expect from granting investment tax incentives? This article offers a partial answer to this question and contributes to the quantitative evaluation of state business taxes. We present a framework that translates a given change in state business tax policy into changes in E&S investment, R&D investment, and overall state economic output. The links among tax policies, investment, and output depend on a set of channels determined by economic theory and a set of parameters whose values are drawn from empirical research. Some of these parameters depend on extant tax policy at the state level, and we provide the information needed for the computations. Other parameters represent structural characteristics of the economy. We rely on prior studies to determine our preferred parameter values, though we also consider the sensitivity of our results to alternative values of these parameters.

Our article proceeds as follows. Section 2 introduces the framework for simulating the impact of state business taxes. The user cost of capital is a fundamental concept linking legislated tax policies to economic incentives. The mobility of capital across states presents a particular challenge for analyzing state tax policy, because the incentive effects of the resulting tax competition must be quantified. A change in incentives affects investment and production through three sets of channels: direct and indirect (reflecting capital mobility and tax competition) user cost channels, substitution and scale channels, and direct production and multiplier channels. All of the relevant economic parameters are discussed. Section 3 reviews the literature and provides some perspective on reasonable ranges for the structural parameters. Section 4 presents state-by-state simulation results for all 48 contiguous states. We illustrate exactly how these results are obtained by walking through the process for one particular state, California. Last, we describe a simple web tool that we have made available online that allows users to insert their own preferred parameter values and simulate the economic effects for the state and tax policy of their choosing. Section 5 summarizes and discusses other state tax policies.

2. A Framework for Simulating the Impact of State Business Taxes

This section develops a framework that links legislated changes in a state's business taxes to resulting changes in the state's stock of equipment and structures capital, its stock of research and development capital, and output.[3] Our framework is depicted in Figure 3. A change in a given tax policy (e.g., a decrease in the corporate income tax rate) affects economic incentives embedded in the user cost of capital (explained later) that, in turn, affect investment and output. These economic variables—the user cost, investment, and output—are linked together by a series of channels that depend on theoretical relations and assumed parameters. (The channels and parameters are summarized in Table 1.) The structural parameter values underlying the simulations are not restricted in our framework, and any values can be inserted in the online applet that accompanies this study. We rely on the literature discussed in Section 3 for guidance on

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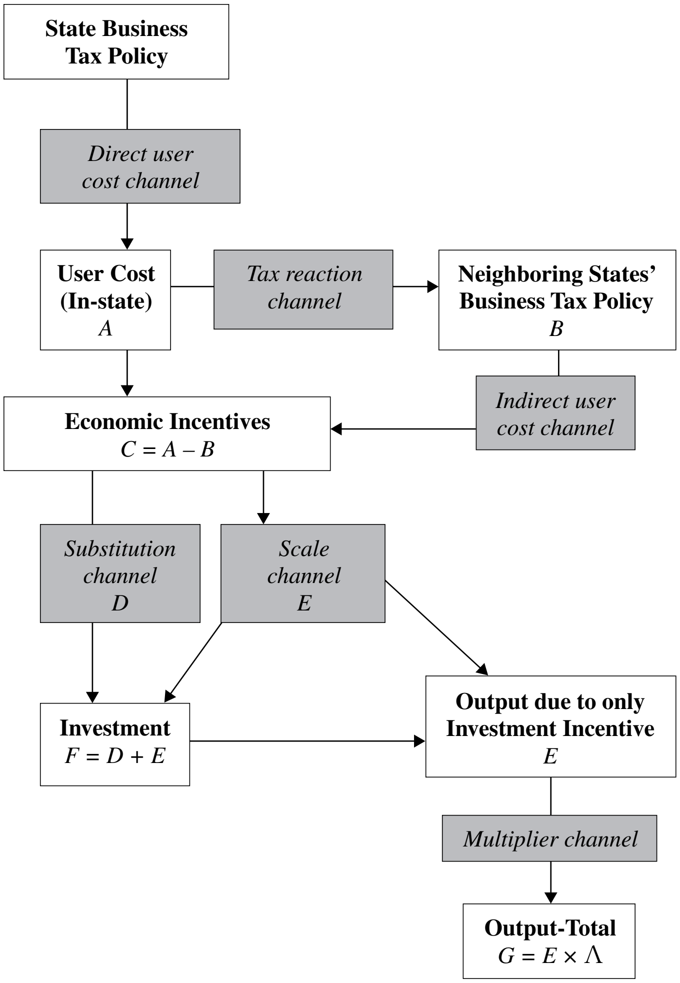
[2] See Wilson (2006) and Gupta et al. (2009) for further discussion of state corporate tax collections and the reason for the decline in recent years.

[3] Technically, the quantity of investment analyzed in this article is net investment, defined as the increase in the capital stock due to the stimulus less depreciation of the existing capital stock. Since we think of depreciation as largely exogenous to the tax policies under consideration, it is not considered explicitly in our analysis.

FIGURE 3
FRAMEWORK RELATING STATE BUSINESS TAX POLICY TO INVESTMENT AND OUTPUT



the range of appropriate parameter choices, and we show in Section 4, through simulations, the sensitivity of the economic effects of business tax policies with different parameter values.

Before proceeding to the specific channels, we note four characteristics of our framework. First, the framework for simulating the impacts of tax policies affecting E&S or R&D investment is the same, though the underlying parameter values will differ. The user cost framework applies equally to the tangible capital built up from past and present E&S investment and to intangible knowledge capital built up from past and present R&D investment. A state's user cost of R&D capital and its user cost of E&S capital will differ due to differences between R&D and E&S in the investment tax credit rate and tax depreciation allowances. Second, the simulations are based on a change relative to the status quo, which differs by state. Third, we restrict our attention to state business taxes and do not consider the additional and potentially important roles of state personal and sales taxes. Fourth, the simulations are most appropriate for economic environments where resources are fully utilized. With this long-run focus, which particularly affects the assumed value for the production multiplier, tax policies designed to stimulate investment in response to a temporary downturn in economic activity would need to be analyzed in a different framework. Our framework is more appropriate for long-run considerations and provides a "roadmap" from tax policy to its ultimate effects on investment and output through three sets of channels we will discuss. But first, we turn to the user cost of capital, the key variable for representing the economic incentives provided by legislated tax policies.

2.1. The User Cost of Capital

The user cost of capital is the fundamental concept for quantifying the effects of tax legislation on capital formation. This concept was introduced by Jorgenson (1963) and is based on the economic equivalence between renting and owning a piece of durable capital. In both cases, the user of that capital good can be thought of as making a periodic payment for capital services. The only difference is that renters of capital are making an explicit payment, whereas owners of capital are effectively renting the capital from themselves and hence making an implicit payment. With this insight, durable capital can be assigned a rental price or user cost that is easy to measure and can be readily analyzed with the standard tools of price theory. Furthermore, the economic impact of several tax policy instruments—investment credits, depreciation allowances, and income taxes—can also be quantified. The user cost provides an enormously convenient framework for translating the effects of legislated tax changes into numerical estimates useful in quantitative policy analysis.

The user cost of capital (UC) depends on several components—the opportunity cost of financial capital, the depreciation of physical capital, the relative price of investment goods, and taxes. The opportunity cost of financial capital, ρ, is the expected return from investing in financial markets, instead of spending the funds on equipment and structures or research and development, and can be specified in several ways that depend on auxiliary assumptions about corporate financing. One approach measures ρ in terms of the real cost of the marginal source of funds—retained earnings (internal equity), external debt, or external equity.[4] Under the

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[4] See Sinn (1991) for a taxonomy of different funding sources and the associated taxes and Auerbach (1983) for the relationship between taxes and corporate financial decisions. The real cost of funds is usually calculated by subtracting an estimate of the expected rate of inflation stated in terms of the producer price. To be consistent with the theoretical derivation of the user cost, the inflation correction should be stated in terms of the price of new investment.

TABLE 1
GLOSSARY OF PARAMETERS AND VARIABLES

PANEL A. STRUCTURAL (NON-STATE-VARYING) PARAMETERS

Parameter	Name	Description
α	Slope of the tax reaction function	The percent change in $UC^{\#}$ for a 1% change in *UC* (where the superscript $^{\#}$ represents neighboring states considered as a singular unit). Range of values {–1.0, +1.0}. (equation 5)
σ	Elasticity of substitution between capital and other factors of production	The percent change in the capital stock with respect to a 1% change in *UC*, holding output and output price constant. Range of values for E&S {0.0, 1.5}; range of values for R&D {0.0, 3.0}. (equation 8)
ω^K	Factor share of capital	Capital's factor share. Range of values for E&S {0.25, 0.50}; range of values for R&D {0.0, 0.1}. (equation 8)
η	Price elasticity of demand for output	The percent change in output demand with respect to a 1 percent change in the price of output. Range of values {0.0, 10.0}. (equation 8)
Λ	Multiplier effect	

PANEL B. STATE-SPECIFIC DATA VARIABLES

Variable	Name	Description
UC	User cost of capital	equation (1)
P^I	Price of new investment goods	equation (1)
P^Y	Price of output	equation (1)
ρ	Opportunity cost of financial capital	equation (1), assumed to be 10 percent.
δ	Rate of economic depreciation	equation (1), estimated from depreciation in the manufacturing sector at the national level.
$ITCR^{R\&D}$	Investment tax credit for research and development	equation (2b)
$ITCR^{E\&S}$	Investment tax credit for equipment and structures	equation (2b)
CITR	Corporate income tax	equation (2b)
TDA	Tax depreciation allowances	equation (2b), set to 0.70 for all states. $TDA = 1$ for the user cost of research and development.
K	Capital stock	
Y	Output	

PANEL C. STATE-SPECIFIC ECONOMIC VARIABLES (CHANNELS)

Channel	Name	Description
A	Direct user cost channel	Parameter A: the percent change in *UC* for a one percentage point change in τ, where τ equals $ITCR^{E\&S}$, $ITCR^{R\&D}$, or *CITR*. See Table 2 for the values of $A_s^{ITCR(E\&S)}$, $A_s^{ITCR(R\&D)}$, and A_s^{CITR} that correspond to the $ITCR^{E\&S}$, $ITCR^{R\&D}$, and the *CITR*, respectively. Note that the *s* subscript reflects that the change in the *UC* with respect to the same change in τ varies by state. (equation 3)
B	Indirect user cost channel	The percent change in $UC^{\#}$ for a one percentage point change in τ and equals $\alpha \times A_s^{ITCR(E\&S)}$, $\alpha \times A_s^{ITCR(R\&D)}$, or $\alpha \times A_s^{CITR}$. (equation 6)
C	Net user cost channel	Direct user cost channel minus indirect user cost channel, $(1-\alpha) \times A_s^{\tau}$. (equation 7)
D	Substitution channel	The percent change in the capital stock with respect to a one percentage point change in τ, holding output constant, $D_s^{\tau} = (\sigma - \sigma \times \omega^k) C_s^{\tau}$.
E	Scale channel	The percent change in the capital stock with respect to a one percentage point change in τ, absent any capital-labor substitution, $E_s^{\tau} = \omega^k \times \eta \times C_s^{\tau}$. E_s^{τ} also gives the percent change in output due directly to the net change in economic incentives.
F	Net investment channel	The percent change in capital stock due to a one percentage point change in τ, $F_s^{\tau} = D_s^{\tau} + E_s^{\tau}$.
G	Multiplier channel	The percent change in total statewide output with respect to a one percentage point change in τ. Leads to the following amount of total output, $G_s^{\tau} = E_s^{\tau} \times \Lambda$.

trade-off theory of capital structure, financial policies equalize the costs of the marginal sources of funds (adjusted for risk and taxes), and thus ρ can be properly measured by either marginal cost. The "pecking order" model also relies on the marginal sources of funds but provides an alternative theory of capital structure that emphasizes asymmetric information in financial markets. In this model, there exists a hierarchy of costs, increasing from internal equity to debt to external equity, and thus our assumptions about the marginal source of funds matter. A third approach measures ρ as a weighted average of the real costs of debt and equity, where the weights represent the proportion of debt and equity in the capital structure. While the marginal funding used in any given year likely differs from the average capital structure reflected in these weights, it must ultimately correspond to the capital structure, and the weighted-average formulation is appropriate for a long-run analysis. The calculations presented in this article sidestep these corporate finance issues and are based on the assumption that $\rho = 10$ percent. This figure is somewhat higher than that used in some other studies but reflects the higher risk premium associated with the manufacturing firms analyzed here.

The next component of the user cost of capital is economic depreciation. Economic depreciation (which differs from tax depreciation discussed later) can be viewed as a "nonrefundable security deposit," reflecting that only a fraction of the rented capital good will be returned at the end of the period because of depreciation. In the standard user cost formula, capital is assumed to depreciate geometrically at rate δ, and our simulations are based on a δ estimated from depreciation in the manufacturing sector at the national level.[5]

The third component of the user cost involves a relative price: the price of new investment goods (P^I) divided by the expected benefit from the output generated by the new unit of capital. For a profit-maximizing firm, the value of that incremental output is its selling price (P^Y). Apart from tax considerations, these three components—the opportunity cost, economic depreciation, and relative prices—lead to the following specification of the user cost,

$$UC = (\rho + \delta) \times (P^I/P^Y). \tag{1}$$

Taxes also affect the user cost of capital, and we consider the roles played by state investment tax credits and the corporate income tax on investment incentives. (For ease of exposition, we do not discuss in this section federal corporate tax policies—that is, the federal R&D tax credit rate, the federal corporate income tax rate, and federal tax depreciation allowances—but they are accounted for in our simulations.) As shown in Figures 1 and 2, state policymakers have frequently sought to stimulate investment by offering tax credits on investment. An investment tax credit is a reduction in a corporation's income tax liability in proportion to the value of investment that the firm does in the state. That proportion is determined by the investment tax credit rate *(ITCR)*. Corporate profits are subject to a corporate income tax that enters the user cost in two ways. In its simplest form, the corporate income tax rate *(CITR)* lowers the pretax income a firm generates from production by a factor of $(1 - CITR)$ multiplied by the price of output appearing in the denominator of the user cost.

Complications arise with tax depreciation allowances that accrue over the useful life of the asset.[6] Since the pioneering work of Hall and Jorgenson (1971), these allowances have been modeled as a present value that depends on tax service lives, tax depreciation patterns, and discount rates. In general, these factors determining depreciation allowances do not vary by state because states normally piggyback on federal IRS depreciation rules. A recent exception is the federal government's temporary accelerated depreciation rules; not all states adjusted their depreciation rules to account for this temporary acceleration. Nonetheless, given that these temporary deviations between state and federal rules are rare, we assume the present value of tax depreciation allowances *(TDA)* is the same across states. The value of *TDA* used in this study is set, for all states, to 0.70 for equipment and structures, slightly lower than the average across asset types reported by Gravelle (1994) in order to make a rough adjustment for the basis reduction due to the investment tax credit. Because 100 percent of R&D investment may be expensed (that is, fully depreciated) in the first year, for all states and at the federal level, *TDA* for R&D is 1.0. Since the benefit of these allowances is to lower the amount of income subject to tax, *TDA* is multiplied by *CITR*. These three tax variables enter the user cost of capital in the following manner:

$$UC = (\rho + \delta) \times (P^I/P^Y) \times TAX \tag{2a}$$

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[5] Even if capital depreciates according to some other pattern, long-run replacement requirements tend to a geometric pattern (Jorgenson 1974).

[6] There are two additional considerations that affect the *CITR* in the user cost formula. First, property taxes enter the user cost in a manner similar to tax depreciation allowances; both involve a stream of commitments that follow upon purchasing an asset. The present value of property taxes enters the user cost both as a direct cost and as a deduction against taxable income; hence the present value of property taxes would be multiplied by $(1 - CITR)$. Second, for determining corporate income tax liability in a given state, corporations that do business in multiple states must apportion their national income to each state using formulary apportionment. The apportionment formula is a weighted average of the company's sales, payroll, and property (E&S capital), but the weights vary by state. The capital weight can be thought of as a capital tax instrument with effects similar to the corporate income tax. We do not have sufficient information to analyze the effects of either the property tax or capital apportionment at the state level.

$$\text{(2b)} \qquad TAX = \frac{1 - ITCR - (CITR \times TDA)}{(1 - CITR)}.$$

Equation (2) captures in a succinct fashion the costs from tax and nontax factors that a profit-maximizing firm faces when evaluating the acquisition of the marginal piece of capital.[7]

There are three considerations to keep in mind in using equation (2) to assess tax policy. First, an important assumption underlying the above derivation of the user cost is that the firm has sufficient profits to pay taxes. Absent this condition, (nonrefundable) tax credits and deductions are not immediately useful, and the calculation of tax incentives becomes considerably more complicated.[8] Second, we assume that the firm does not face a corporate alternative minimum tax. Third, for firms whose cost of external finance exceeds that for internal funds, tax cuts provide two stimuli. Changing internal finance affects the behavior of financially constrained firms over and above the incentive represented by variations in the user cost. A higher investment tax credit, for example, may have standard incentive effects on the demand for capital but, for financially constrained firms, the resulting increase in cash flow raises capital formation further than if the firm did not face finance constraints. While these three factors may affect the quantitative impact of tax policy in the short run, they will have much less impact on the long-run calculations that are the focus of this article.

2.2. Investment Incentives via Direct and Indirect User Cost Channels

There are two channels through which changes in a state's tax policy may affect the state's user cost of capital and, in turn, investment and output. We illustrate these two channels by considering a tax policy change by the state of California. The first channel is the direct user cost channel whereby the change in one of California's tax variables discussed above implies a change in California's user cost. The second, which we call the indirect user cost channel, is more complex. Because capital (either E&S or R&D) in its pursuit of the highest net-of-tax return may well be mobile across states, investment in California can be affected by the user costs of capital in other "neighboring" states (which we discuss further in the literature review in Section 3). In addition, policymakers in the neighboring states may react to the California tax change, a phenomenon known as tax competition. Thus, the California tax change will not only have a direct effect on California's investment by changing California's user cost, but also an indirect effect on California investment by changing the user costs in neighboring states.

We first consider the percentage change in *UC* due to a one percentage point decrease in *CITR* that leads to the following *direct user cost channel.* (Note that the equation is the same whether the *UC* refers to an E&S or R&D investment, though parameter values will differ.)

$$\text{(3)} \quad \frac{\partial UC/UC}{-\partial CITR} = \frac{-1.0}{(1 - CITR)} + \frac{(TDA)}{(1 - CITR) \times TAX} \equiv A_s^{CITR}.$$

A decrease in *CITR* has two opposing effects. Of the two terms in the middle expression in equation (3), the first term captures a decline in *UC* because the lower *CITR* raises the net-of-tax return from a unit of output. But the lower *CITR* also implies that the value of tax deductions associated with *TDA* is worth less, thus raising *UC*. This latter effect is captured by the second term. In our data, A_s^{CITR} is always negative for the E&S user cost, but always positive for the R&D user cost. The magnitude of the decrease in *UC* depends on all tax variables discussed above. Since some of these tax variables vary by state, equation (3) is evaluated on a state-by-state basis. (We have added a subscript *s* to indicate that the effect varies by state.)

A one percentage point increase in the *ITCR* creates an alternative *direct user cost channel* (stated as a percentage change),

$$\text{(4)} \qquad \frac{(\partial UC/UC)}{\partial ITCR} = \frac{-1}{(1 - CITR) \times TAX} \equiv A_s^{ITCR(E\&S)} \ \left(\text{or } A_s^{ITCR(R\&D)}\right).$$

The increase in *ITCR* lowers *UC*. As with the change in *CITR*, equation (4) is evaluated on a state-by-state basis and differs for E&S and R&D user costs. We refer to the percentage change in the user costs for E&S and R&D by parameters $A_s^{ITCR(E\&S)}$ and $A_s^{ITCR(R\&D)}$, respectively.

As discussed earlier, the indirect user cost channel captures the effect that a change in a given state's tax policy may have on other states' tax policies (via tax competition) and, in turn, other states' user costs of capital. Recall that other states' user costs could negatively affect investment in a given state to the extent that investment is geographically mobile or "footloose." Letting a superscript # represent the neighboring states considered as a singular unit, we compute the following *tax reaction channel* relating the percentage change in $UC^{\#}$ to a given percentage change in *UC*,

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[7] For additional details about the construction of the user cost, see King and Fullerton (1984), Cordes, Ebel, and Gravelle (2005), and Chirinko and Wilson (2008, Appendix; 2009b).

[8] See Auerbach and Poterba (1987), Mintz (1988), Altschuler and Auerbach (1990), and Devereux, Keen, and Schiantarelli (1994) for further discussion of tax incentives and tax-loss status. A few states have a refundable investment tax credit whereby a business in a tax-loss position can receive a direct payment from the state for the value of the credit.

$$(5)\qquad \frac{(\partial UC^{\#}/UC^{\#})}{(\partial UC/UC)} \equiv \alpha.$$

The actual change in investment incentives due to the one percentage point change in *CITR* or *ITCR* is the product of the implied change in *UC* determined by equations (3) or (4), respectively, and the change in $UC^{\#}$ determined by equation (5). This interaction leads to the following indirect user cost channel for *CITR*, $ITCR^{E\&S}$, and $ITCR^{R\&D}$,

$$(6a)\qquad \frac{(\partial UC^{\#}/UC^{\#})}{(\partial UC/UC)} \times \frac{(\partial UC/UC)}{\partial ITCR^{CIT}} = \alpha \times A_s^{CITR} \equiv B_s^{CITR}.$$

$$(6b)\qquad \frac{(\partial UC^{\#}/UC^{\#})}{(\partial UC/UC)} \times \frac{(\partial UC/UC)}{\partial ITCR^{E\&S}} = \alpha \times A_s^{ITCR(E\&S)} \equiv B_s^{ITCR(E\&S)},$$

$$(6c)\qquad \frac{(\partial UC^{\#}/UC^{\#})}{(\partial UC/UC)} \times \frac{(\partial UC/UC)}{\partial ITCR^{R\&D}} = \alpha \times A_s^{ITCR(R\&D)} \equiv B_s^{ITCR(R\&D)},$$

Equations (3) through (6) quantify the economic incentives for investment in a given state due to a change in tax policy. The net effect on economic incentives for a given tax instrument (τ) in state *s* is represented by C_s^{τ}, the difference between A_s^{τ} and B_s^{τ},

$$(7)\qquad C_s^{\tau} \equiv A_s^{\tau} - B_s^{\tau} = (1-\alpha)A_s^{\tau} \qquad \tau = \{CITR, ITCR^{E\&S}, ITCR^{R\&D}\},$$

Equation (7) represents how much (in percentage terms) the user cost in a given state changes relative to how much user costs in neighboring states change. Traditional neoclassical production theory implies that only the in-state user cost matters for economic incentives (that is, $\alpha = 0$). We diverge from the traditional theory and posit that this relative difference determines economic incentives.

2.3. Investment via Substitution and Scale Channels

The change in economic incentives represented by equation (7) is translated into changes in investment *I* through standard microeconomic substitution and scale channels.[9] A particularly convenient formula has been derived by Hicks (1932/1963) that quantifies these two channels in terms of a limited set of parameters describing the production function and market conditions faced by the firm. Hicks's formula is written as follows,

$$(8)\qquad \frac{(\partial I/I)}{-(\partial UC/UC)} = \sigma - \sigma \times \omega^{K} + \omega^{K} \times \eta,$$

where σ is the elasticity of substitution between capital and the other factors of production, ω^{K} is the factor share of capital (i.e., the portion of the value of output devoted to capital costs), and η is the price elasticity of demand for output.[10] Note that these parameters will vary by E&S and R&D capital, though our derivation here does not explicitly recognize these differences.

Equation (8) captures in a succinct manner the substitution and scale effects that link a change in the user cost to the change in investment. Suppose that the user cost has fallen because of a decrease in *CITR* or an increase in *ITCR*. The first term on the right side of equation (8), σ, represents a substitution effect holding output and its price constant. The larger σ is, the more that firms will substitute capital for labor (and other factors of production) for a given change in *UC*. The second term represents an additional substitution effect driven by the lower marginal cost of production. Under competitive conditions, the decline in marginal cost due to the lower user cost translates into a decline in the output price. The extent of this decline is determined by the relative importance of capital in production, as represented by ω^{K}. The decline in the output price raises the relative price of capital and lowers demand for capital (cf. equation 2); hence the negative sign in equation (8). The net substitution effect resulting from a specific tax policy change—a one percentage point reduction in *CITR* or a one percentage point increase in *ITCR*—is measured by $\sigma - \sigma \times \omega^{K}$ multiplied by the effect of the policy change *UC*. This substitution effect is represented by $D_s^{\tau} = (\sigma - \sigma \times \omega^{K}) \times C_s^{\tau}$.

The third term in equation (8), $\omega^{K} \times \eta$ represents the impact of a lower output price that allows the firm to slide down the product demand curve and increase output. Firms in markets where customers are very price-sensitive are able to reap greater benefits from being able to reduce the price of their output and hence will produce more. As with the substitution effect, the magnitude of this scale effect, E_s^{τ}, in response to a specific tax policy change, will be the product of the effect of a change in the user cost on investment, $\omega^{K} \times \eta$, multiplied by the effect of the policy change on the user cost, C_s^{τ}. This scale effect is represented by $E_s^{\tau} = \omega^{K} \times \eta \times C_s^{\tau}$.

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[9] In our long-run analysis, no difference exists between changes in investment and changes in the capital stock *(K)*. This equivalence holds because, in the long-run, investment is proportional to the capital stock, with proportionality factor equal to the sum of the depreciation and long-run growth rates. Hence the percentage change in investment equals the percentage change in the capital stock that, in turn, equals the percentage change in the user cost multiplied by parameters reflecting substitution and scale effects (cf. equation 8).

[10] See Chirinko and Mallick (2009) for a derivation and further discussion of Hicks's formula.

Combining the direct and indirect user cost channels that affect investment incentives and the substitution and scale channels that affect investment, we can represent the impact of a one percentage point decrease in *CITR* or increase in *ITCR* by $F_s^\tau = D_s^\tau + E_s^\tau$.

2.4. Output via Scale and Multiplier Channels

State tax policy affects the amount of output produced by firms through scale and multiplier channels. The scale channel is the same as the one that affects investment in the preceding subsection whereby a reduction in the user cost of capital lowers the marginal cost of production that, in turn, lowers the price of and raises the demand for output. As stated above, the scale effect is represented by $E_s^\tau = \omega^K \times \eta \times C_s^\tau$.[11]

Many studies of tax and other government policies introduce a multiplier channel, arguing that the spending generated from the policy initiative will stimulate additional rounds of spending and production. We are not comfortable with multiplier analyses. For the long run we focus on in this article, the additional resources needed in the multiplier rounds of spending must be drawn away from other activities. Thus, while it is possible that the tax policy stimulates activity in one sector, this increase will be at the expense of other sectors. The net effect could be close to zero in the long run. There may be greater scope for multiplier analysis in the short run, but multiplier parameters are not usually based on models that allow for a temporary period of deficient demand and a gradual transition to a long run with reasonable steady-state properties. These caveats notwithstanding, we allow for the possibility of multiplier effects; specifically, we multiply the output from the direct production channel, E_s^τ, by Λ. The parameter Λ reflects assumptions about the size of the multiplier and varies from 0 to whatever number may be of interest. A value below 1.0 suggests negative within-state externalities from the direct production effect. For example, if the induced investment and increased production by firms that benefit from a tax change crowd out investment and production by other firms in the state, then Λ could be less than one. Total output arising from the tax policy is represented by $G_s^\tau = E_s^\tau \times \Lambda$.

3. A Brief Literature Review

This section offers a brief review of several papers and issues that are relevant for determining the values of the some of the key parameters and the economic variables introduced in Section 2. Note that channels B through G are transformations of these "primitive" economic variables and parameters and that channel A is determined by variables entering the user cost formula in equation (2). See Table 1 for a glossary providing the symbols, names, and descriptions of each of the parameters and variables used in this article.

It is worth commenting on five parameters that are central to the simulation results. First, the elasticity of substitution between capital and labor, $-\sigma$, plays a central role in determining the size of the substitution channel, and thus it is very important in assessing the quantitative impact of business tax policies. Given certain assumptions about the production function, $-\sigma$ turns out also to be the elasticity of the capital-output ratio with respect to a change in the user cost of capital *(UC)*. An increase in the user cost must have a nonpositive effect on capital demand, so $-\sigma \leq 0$. The larger σ is, the more responsive capital formation is to a given change in the user cost. Estimates in the literature have varied widely. The largest values tend to cluster around 1.0, a value consistent with a Cobb-Douglas production function. Other studies have reported much lower estimates. Chirinko (2008) reviews a large number of studies and concludes that the weight of the evidence suggests a value for σ ranging from 0.40 to 0.60.

Chirinko and Wilson (2008) estimate this parameter for a panel of states in a model with the user cost (current and lagged) and report that σ equals 0.71. When the user cost for neighboring states is included and the model estimated with a relative user cost variable, the value of σ equals 0.76.[12] In this article, we use this as our preferred estimate.

Second, the slope of the reaction function of the user costs in a given state (e.g., California) and its "neighboring" states governs how states might react to one another's policy changes. Practical considerations dictate that the user costs for the neighboring states be condensed into a single variable, and the standard procedure in the literature is to use spatial weights to aggregate all of California's neighboring states. The weights can be defined in several ways. In this study, we use weights based on geographic proximity—i.e., the inverse of the distance between the population centroids of California and all other 47 contiguous states.[13] Thus, all 47 states are

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[11] It may seem odd that the scale channels for investment and output are equal. However, it should be kept in mind that the scale channel is stated as a percentage change. In the previous subsection, investment is raised by E_s^τ percent. When evaluating the response of output, both capital and other factors of production (e.g., labor) are raised by equal percentages of E_s^τ percent. In turn, the extra capital and labor are weighted by their respective factor shares. Since the factor shares sum to one, the effect on output is just the initial shock, E_s^τ percent.

[12] This value comes from Column 12 of Table 2 in Chirinko and Wilson (2008).

[13] We use Census Bureau data on the latitude and longitude of states' population centroids and what is known as the "great circle distance formula," which accounts for the curvature of the earth, to calculate distances between states.

California's neighbors, with Nevada receiving a large weight and New York a very small weight. Alternative weighting schemes used in the literature include population weights (which would give New York a much larger impact on California), bordering states (which would give New York a zero weight for California), and commodity trade flows (based on the shipments of goods from and to California from a given state, a procedure which would give New York a weight between the values from the two other weighting schemes).

Given a definition of neighboring states, the slope of the reaction function for business taxes has been estimated in many studies, all but one of which find that the slope is positive.[14] As one example of this class of studies, Devereux, Lockwood, and Redoano (2008) find a value of α equal to 0.70 for the slope of the reaction function among countries in the European Union in terms of their corporate income tax rate. By contrast, Chirinko and Wilson (2009a) look at U.S. states and find that, when time lags and aggregate time effects are properly accounted for, the slope of the reaction function is negative. Their preferred estimates of α are –0.59 for $ITCR^{E\&S}$ and –0.08 for *CITR*, which we use in our benchmark simulation for this article. While the negative signs are surprising given the extant literature, they are fully consistent with a theoretical model in which the marginal preference of the representative voter for private goods relative to public goods with respect to an increase in income is positive. Thus, the α parameter can range widely, though considerations of stability require that the absolute value of the slope be less than one. We are unaware of any studies estimating the slope of the reaction function for the R&D investment tax credit. In our simulations, we will assume that the slope for the R&D credit is the same as that for the E&S credit.

A third important parameter in our framework is the price elasticity of demand for output, $-\eta$. This parameter plays a large role in macroeconomics, both in calibrating dynamic stochastic general equilibrium models and in assessing the role of market power on economic fluctuations. Econometric estimates of η (or other parameters from which η can be deduced) based on industry data have ranged widely from 1.04 (Chang, Hornstein, and Sarte 2009) to 4.68 (Chirinko and Fazzari 1994). The η parameter can also be inferred from industry accounting data on sales and costs. These estimates range from 2.59 (Chirinko and Fazzari 1994) to 3.45 (Domowitz, Hubbard, and Petersen 1987). These latter estimates are based on average costs that more closely measure long-run costs and long-run behavior than the econometric estimates. We use 3.0 as our benchmark value of η.

The parameter Λ reflects the additional rounds of spending and production that may follow from the output that is directly related to the tax policy. We noted our reservations about this parameter in subsection 2.4. Our simulation results below assume neither a positive nor a negative multiplier effect; hence, $\Lambda = 1$.

Last, capital's factor share in production, ω^{K}, is a parameter that can be measured directly from the data. This parameter plays a critical role in determining the magnitude of both substitution and scale effects. Given that compensation data are usually more readily available than data on payments to capital, this variable can be estimated as one minus labor's factor share. Estimates range from 0.25 to 0.50 for all capital, including E&S and R&D. We use $\omega^{E\&S} = 0.30$ and $\omega^{R\&D} = 0.05$ as baseline values in our model simulations.

4. Simulation Results: Predicted Responses of Investment and Output to Tax Policy Changes

This section contains a variety of simulation results by state, based on the framework described in Section 2 for hypothetical changes in three tax policies—*CITR*, $ITCR^{E\&S}$, and $ITCR^{R\&D}$. Subsection 4.1 presents the responses of investment and output to these tax policies based on our preferred structural parameters. As the discussion in Section 3 indicated, however, there is uncertainty over the precise values of these structural parameters, and subsection 4.2 documents the sensitivity of the results to alternative parameter values. To allow users flexibility, we have developed an online applet discussed in subsection 4.3 that permits users to choose their preferred parameter values.

4.1. Preferred Parameters

Results for our preferred parameters are shown in Tables 2 through 4. The first two columns of Table 2 contain the percentage changes in the user cost of capital due to a one percentage point decrease in *CITR* (column 1) and a one percentage point increase in $ITCR^{E\&S}$ (column 2). These computations are based on equations (3) and (4), respectively. The user cost differs for E&S and R&D capital by the value of the investment tax credit for either type of capital. Columns 3 and 4 present comparable calculations for R&D capital, specifically the percentage changes in the user cost of capital due to a one percentage point decrease in *CITR* (column 3) and a one percentage point increase in $ITCR^{R\&D}$ (column 4). The entries in Table 2 reflect both the direct and indirect user cost channels linking tax policy to economic incentives.

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[14] See Heyndels and Vuchelen (1998), Brueckner and Savaadra (2001), Hayashi and Boadway (2001), Altschuler and Goodspeed (2002), Revelli (2002), Devereux, Lockwood, and Redoano (2008), and Overesch and Rincke (2009). Brueckner (2006) surveys the literature estimating tax reaction functions.

At least four observations can be made about the results in Table 2. First, there is a great deal of variation in the response of user cost to different tax instruments. A one percentage point increase in $ITCR^{E\&S}$ or $ITCR^{R\&D}$ has a much larger effect on UC than a one percentage point decrease in $CITR$. Second, for a given tax instrument, there is much less variation across states. For example, the unweighted average change in the E&S user cost due to a one percentage point decrease in $CITR$ is −0.66 percent, and the comparable entries in column 1 cluster rather closely around this average. Third, the decrease in $CITR$ has radically different effects on economic incentives, decreasing the E&S user cost (column 1) but increasing the R&D user cost (column 3). This difference in $CITR$'s effect on E&S versus R&D is traceable to different values of TDA. E&S capital is depreciated over several years. Given the time value of money, $TDA^{E\&S}$ is less than 1.0; our simulations are based on a value of 0.70. By contrast, R&D capital is expensed, and hence $TDA^{R\&D}$ equals 1.0. When equation (4) is evaluated with this relatively higher value of TDA, the second term dominates, and the derivative is positive. Intuitively, the drop in $CITR$ removes one of the primary tax advantages of R&D investment vis-à-vis E&S investment, thereby lowering incentives to invest in R&D and raising incentives to invest in E&S. Fourth, the increase in the $UC^{R\&D}$ is larger for those states with R&D investment tax credits (cf. equation (4) where the $(1/TAX)$ term will be larger the larger is $ITCR^{R\&D}$). For example, California has one of the largest effective R&D credit rates with its $ITCR^{R\&D}$ equal to 13.7 percent and the second largest increase in $UC^{R\&D}$. The positive entries in column 3 indicate that a decrease in $CITR$ actually increases the user cost qua price of R&D investment, thus increasing incentives for firms to substitute away from relatively costly R&D capital towards E&S capital, labor, and other factors of production.

Columns 1 and 2 of Table 3 show the predicted increases in E&S investment in response to the hypothetical tax policy changes mentioned earlier. The patterns are driven by the effects of the tax policy changes on user costs (Table 2) multiplied by parameters reflecting substitution and scale effects. For example, according to Table 2, a one percentage point decrease in $CITR$ lowers California's user cost by –0.71 percent. This decrease is multiplied by 1.54, equal to our preferred values of the parameters entering the right side of equation (8). This multiplicative factor links each of the state entries in Table 2 to the corresponding state entries in Table 3. Columns 3 and 4 show the predicted change in R&D investment in response to a decrease in $CITR$ and an increase in $ITCR^{R\&D}$. As indicated in the discussion of Table 2, the former effect is negative and the latter is positive.

Table 4 presents the predicted changes in state output in response to each of the three hypothetical tax policy changes.

TABLE 2
EFFECT OF SELECTED TAX POLICIES ON E&S OR R&D USER COSTS OF CAPITAL, BY STATE

	Change in E&S user cost due to 1 percentage point change		Change in R&D user cost due to 1 percentage point change	
State	drop in $CITR$	increase in $ITCR^{E\&S}$	drop in $CITR$	increase in $ITCR^{R\&D}$
Alabama	–0.59%	–2.35%	0.42%	–2.81%
Arizona	–0.69	–2.29	1.09	–2.73
Arkansas	–0.53	–2.63	0.45	–3.24
California	–0.71	–2.36	1.38	–2.85
Colorado	–0.66	–2.20	0.43	–2.60
Connecticut	–0.63	–2.45	0.77	–2.98
Delaware	–0.70	–2.37	0.52	–2.86
Florida	–0.67	–2.23	0.44	–2.65
Georgia	–0.56	–2.53	0.99	–3.08
Idaho	–0.66	–2.40	0.71	–2.90
Illinois	–0.68	–2.32	0.48	–2.78
Indiana	–0.70	–2.35	1.06	–2.83
Iowa	–0.65	–2.60	0.86	–3.20
Kansas	–0.68	–2.33	0.47	–2.80
Kentucky	–0.69	–2.29	0.45	–2.74
Louisiana	–0.67	–2.22	0.84	–2.64
Maine	–0.71	–2.36	0.49	–2.85
Maryland	–0.69	–2.29	0.50	–2.74
Massachusetts	–0.67	–2.49	1.09	–3.05
Michigan	–0.62	–2.13	0.40	–2.49
Minnesota	–0.72	–2.40	0.61	–2.91
Mississippi	–0.59	–2.37	0.43	–2.85
Missouri	–0.67	–2.22	0.46	–2.63
Montana	–0.68	–2.28	0.70	–2.72
Nebraska	–0.54	–2.69	0.47	–3.34
Nevada	–0.61	–2.04	0.38	–2.37
New Hampshire	–0.71	–2.38	0.48	–2.87
New Jersey	–0.71	–2.37	1.08	–2.86
New Mexico	–0.69	–2.31	0.46	–2.77
New York	–0.64	–2.44	0.46	–2.96
North Carolina	–0.61	–2.47	0.59	–3.00
North Dakota	–0.66	–2.20	0.61	–2.60
Ohio	–0.68	–2.41	0.50	–2.92
Oklahoma	–0.66	–2.28	0.44	–2.72
Oregon	–0.68	–2.27	0.69	–2.71
Pennsylvania	–0.72	–2.41	0.53	–2.92
Rhode Island	–0.65	–2.51	1.73	–3.07
South Carolina	–0.66	–2.21	0.67	–2.62
South Dakota	–0.61	–2.04	0.38	–2.37
Tennessee	–0.67	–2.30	0.45	–2.75
Texas	–0.66	–2.19	0.66	–2.60
Utah	–0.66	–2.21	0.72	–2.62
Vermont	–0.65	–2.58	0.53	–3.18
Virginia	–0.67	–2.25	0.44	–2.68
Washington	–0.61	–2.04	0.38	–2.37
West Virginia	–0.64	–2.55	0.63	–3.12
Wisconsin	–0.70	–2.32	0.70	–2.79
Wyoming	–0.61	–2.04	0.38	–2.37
Unweighted average	–0.66%	–2.33%	0.63%	–2.80%

TABLE 3
EFFECT OF TAX POLICIES ON CAPITAL STOCK BY STATE

	Change in E&S capital due to 1 percentage point change		Change in R&D capital due to 1 percentage point change	
State	drop in *CITR*	increase in $ITCR^{E\&S}$	drop in *CITR*	increase in $ITCR^{R\&D}$
Alabama	0.90%	5.34%	–1.16%	11.27%
Arizona	1.06	5.20	–2.96	10.97
Arkansas	0.81	5.98	–1.22	12.99
California	1.09	5.37	–3.76	11.42
Colorado	1.02	5.00	–1.16	10.43
Connecticut	0.97	5.58	–2.09	11.94
Delaware	1.08	5.39	–1.41	11.46
Florida	1.03	5.07	–1.19	10.63
Georgia	0.86	5.75	–2.69	12.36
Idaho	1.01	5.45	–1.94	11.61
Illinois	1.05	5.27	–1.30	11.14
Indiana	1.09	5.34	–2.88	11.34
Iowa	1.00	5.91	–2.33	12.85
Kansas	1.04	5.31	–1.29	11.24
Kentucky	1.06	5.20	–1.23	10.97
Louisiana	1.03	5.06	–2.29	10.59
Maine	1.09	5.38	–1.34	11.44
Maryland	1.06	5.20	–1.35	10.97
Massachusetts	1.04	5.67	–2.97	12.21
Michigan	0.96	4.83	–1.09	9.99
Minnesota	1.11	5.46	–1.67	11.66
Mississippi	0.92	5.40	–1.17	11.44
Missouri	1.03	5.05	–1.24	10.56
Montana	1.05	5.18	–1.90	10.91
Nebraska	0.83	6.13	–1.28	13.40
Nevada	0.94	4.63	–1.05	9.49
New Hampshire	1.10	5.41	–1.30	11.52
New Jersey	1.10	5.38	–2.93	11.46
New Mexico	1.07	5.26	–1.25	11.12
New York	0.98	5.55	–1.25	11.88
North Carolina	0.93	5.62	–1.62	12.04
North Dakota	1.02	5.00	–1.66	10.44
Ohio	1.04	5.49	–1.35	11.72
Oklahoma	1.02	5.19	–1.20	10.92
Oregon	1.05	5.17	–1.89	10.88
Pennsylvania	1.11	5.48	–1.45	11.71
Rhode Island	1.01	5.70	–4.70	12.29
South Carolina	1.02	5.03	–1.81	10.52
South Dakota	0.94	4.63	–1.05	9.49
Tennessee	1.03	5.23	–1.22	11.04
Texas	1.01	4.99	–1.79	10.41
Utah	1.02	5.03	–1.96	10.52
Vermont	0.99	5.87	–1.44	12.74
Virginia	1.04	5.11	–1.20	10.74
Washington	0.94	4.63	–1.05	9.49
West Virginia	0.98	5.79	–1.70	12.52
Wisconsin	1.07	5.28	–1.89	11.19
Wyoming	0.94	4.63	–1.05	9.49
Unweighted average	1.01%	5.30%	–1.72%	11.24%

TABLE 4
EFFECT OF TAX POLICIES ON OUTPUT BY STATE

	Increase in output due to 1 percentage point change		
State	drop in *CITR*	increase in $ITCR^{E\&S}$	increase in $ITCR^{R\&D}$
Alabama	0.50%	3.35%	0.67%
Arizona	0.49	3.27	0.65
Arkansas	0.44	3.76	0.77
California	0.46	3.37	0.68
Colorado	0.57	3.14	0.62
Connecticut	0.49	3.50	0.71
Delaware	0.60	3.39	0.68
Florida	0.58	3.19	0.63
Georgia	0.38	3.61	0.73
Idaho	0.52	3.42	0.69
Illinois	0.58	3.31	0.66
Indiana	0.51	3.35	0.67
Iowa	0.49	3.71	0.76
Kansas	0.58	3.34	0.67
Kentucky	0.59	3.27	0.65
Louisiana	0.51	3.18	0.63
Maine	0.61	3.38	0.68
Maryland	0.59	3.27	0.65
Massachusetts	0.48	3.56	0.73
Michigan	0.54	3.04	0.59
Minnesota	0.60	3.43	0.69
Mississippi	0.51	3.39	0.68
Missouri	0.57	3.17	0.63
Montana	0.55	3.26	0.65
Nebraska	0.45	3.85	0.80
Nevada	0.53	2.91	0.56
New Hampshire	0.61	3.40	0.68
New Jersey	0.51	3.38	0.68
New Mexico	0.60	3.30	0.66
New York	0.54	3.49	0.71
North Carolina	0.49	3.53	0.72
North Dakota	0.54	3.14	0.62
Ohio	0.58	3.45	0.70
Oklahoma	0.57	3.26	0.65
Oregon	0.55	3.25	0.65
Pennsylvania	0.61	3.44	0.70
Rhode Island	0.35	3.58	0.73
South Carolina	0.54	3.16	0.62
South Dakota	0.53	2.91	0.56
Tennessee	0.57	3.29	0.66
Texas	0.53	3.13	0.62
Utah	0.53	3.16	0.62
Vermont	0.54	3.69	0.76
Virginia	0.58	3.21	0.64
Washington	0.53	2.91	0.56
West Virginia	0.52	3.64	0.74
Wisconsin	0.56	3.32	0.66
Wyoming	0.53	2.91	0.56
Unweighted average	0.53%	3.33%	0.67%

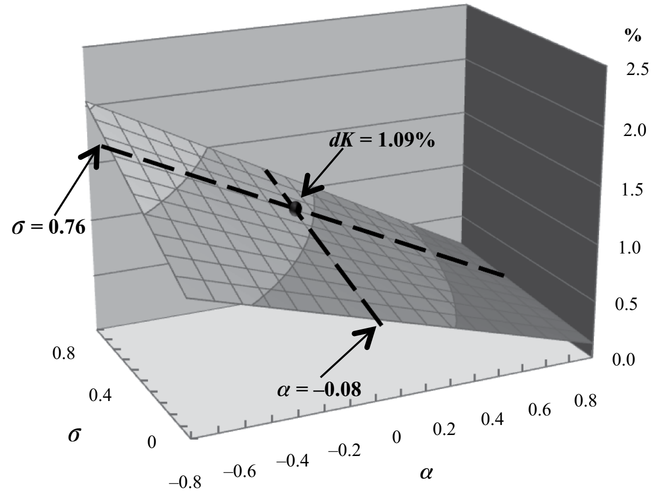
The predicted changes are based on the scale effect described in subsections 2.3 and 2.4. For changes in $ITCR^{E\&S}$ and $ITCR^{R\&D}$, the change in output equals the product of capital's income share (ω^K), the price elasticity of demand for output (η), and the percentage change in the user cost (Table 2, columns 2 and 4, respectively). For a change in *CITR*, the change in output is the sum of the change in output due to changes in $UC^{E\&S}$ ($\omega^{E\&S} \times \eta \times$ entry in Table 2, column 1) and $UC^{R\&D}$ ($\omega^{R\&D} \times \eta \times$ entry in Table 2, column 3). The increase in $ITCR^{E\&S}$ has a substantially larger impact on output than $ITCR^{R\&D}$ because R&D plays a much smaller role in production: R&D's average share of production costs in U.S. manufacturing is lower than E&S's share by a factor of six (i.e., $\omega^{E\&S} = 6 \times \omega^{R\&D}$). The predicted increase in output due to $ITCR^{E\&S}$ is also much larger than the predicted increase due to *CITR* because the latter has a relatively smaller impact on the user cost (Table 2, columns 1 and 3). It is possible that a multiplier effect could make the predicted increases reported in Table 4 smaller or larger, though, as discussed earlier, we suggest caution when inserting multiplier assumptions.

4.2. Sensitivity to Alternative Parameter Values

The simulation results presented in the previous subsection are based on a set of parameters that we believe most accurately characterize relevant structural features of the economy. However, Section 3 highlights that other values of these parameters are also quite plausible. In order to assess the sensitivity of the simulation results to alternative values, we recompute our simulations for California and present the results in three-dimensional figures that plot a wide range of parameter values on two of the axes and the predicted increases in investment or output on the vertical axis. Seven figures are presented, and they parallel the seven columns of results presented in Tables 3 and 4.

Figures 4 to 7 report predicted increases in E&S and R&D investment for alternative values of the elasticity of substitution between capital and other factors of production (σ) and the slope of the tax reaction function (α). Our preferred parameter values are indicated with the dashed black lines in each figure, and their intersection, which indicates our predicted increase in investment given these preferred parameter values (and matches the values in Tables 3 and 4 for California), is shown as a circle. For example, Figure 4 shows the response of E&S investment to a decrease in *CITR*. Here, our preferred parameter values of $\sigma = 0.76$ and $\alpha = -0.08$ yield a predicted increase in investment of 1.09 percent for a one percentage point decrease in *CITR*. Figure 4 allows σ to vary between 0.0 and 1.0 and α between –0.8 and +0.8. The variations in σ have a modest effect on the predicted increase in investment. Holding α fixed at –0.08, the predicted increases in investment rise to 1.22 percent when σ is at its upper bound of 1.0 and fall to 0.69 percent when σ is at its lower bound of 0.0. The latter result represents a situation where the substitution channel is completely inoperative, and the investment increase is solely from the scale channel. More dramatic changes occur with variations in α. The predicted increase in investment from a decrease in *CITR* falls with α. An upper bound value of 0.80 for α represents very competitive responses by neighboring states and severely diminishes the economic incentive and incremental investment from a tax policy change. As α varies from −0.8 to +0.8, the predicted increase in investment falls from 1.83 to 0.20 percent. Similar results presented in Figure 5 hold

FIGURE 4
PREDICTED INCREASE IN E&S INVESTMENT DUE TO 1 PERCENTAGE POINT DROP IN *CITR*
(for various values of tax competition slope (α) and relative user cost elasticity (σ))



Notes: Figures 4 through 10 are three-dimensional surface charts describing the sensitivity of the economic impact (investment or output) of a change in tax policy to variations in selected parameters. For example, in Figure 4, the height of the surface (z axis) indicates the percentage change in a state's investment (*dI/I* (= *dK/K*, per footnote 9)) resulting from a one percentage point reduction in the state's corporate income tax rate *(CITR)*, based on our simulations and data for 2006 for the state of California. The size of the impact, *dI/I*, depends on several variables and parameters. Figure 4 highlights the sensitivity of impact to two key economic parameters: the slope of the *CITR* interstate reaction function (α), which varies along the x axis, and the elasticity of the capital with respect to the relative user cost of capital (σ), which varies along the y axis. Note that the height of the three-dimensional surface shown in the figure varies by state, but the shape of the surface does not change. For instance, while *dI/I* = 1.09% is specific to California, the sensitivities of *dI/I* to α and σ is qualitatively the same for all states.

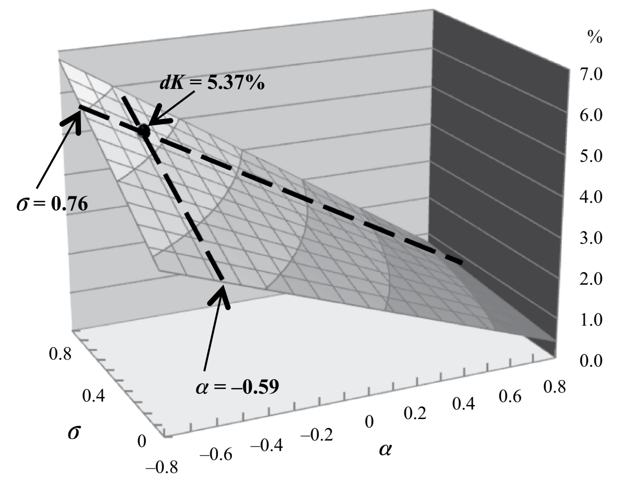
The dashed line at $\alpha = -0.08$ indicates the *CITR* reaction function slope estimated in Chirinko and Wilson (2009a); the dashed line at $\sigma = 0.76$ indicates the relative user cost elasticity estimated in Chirinko and Wilson (2008). The point where these lines intersect, shown as a ball in the chart, therefore reflects our best estimate of exactly how much the capital stock in California would increase if the state were to reduce its corporate income tax rate by one percentage point.

for the predicted increase in investment from an increase in *ITCR*.

Figures 6 and 7 present comparable results for R&D investment. For these R&D figures, we vary σ over a wider range (0.0 to 3.0) than we did for the E&S figures. We do so because our preferred value of 2.5, based on the estimates found in Wilson (2009), are much larger than the range of values typically found for the E&S elasticity of substitution. The sensitivity of the simulation results to α remains. Variations in σ have a more dramatic effect than was evident in Figures 4 and 5, though this is primarily due to the wider range of values for σ in Figures 6 and 7. Owing to R&D's small share of capital income, the scale effect for R&D investment is very small. Thus, as σ approaches 0.0 and the substitution effect is eliminated, the predicted increase in investment also approaches 0.0.

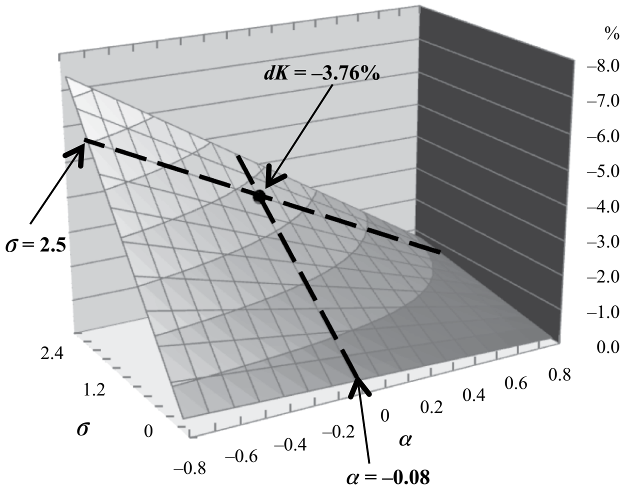
The sensitivity of the predicted increases in output are presented in Figures 8 to 10 for alternative values of α and the price elasticity of demand for output (η), the latter ranging from 0.0 to 5.0. As with the prior figures, the simulation results are very sensitive to α. For example, a one percentage point increase in $ITCR^{E\&S}$ results in a 3.37 percent increase in output for our benchmark parameters. This predicted increase (Figure 9) falls to 2.12 percent and 0.42 percent when α equals 0.00 and 0.80, respectively. Since the scale effect is proportionate to η, this parameter also has substantial influence on the predicted output resulting from changes in each of the three tax variables. In Figure 9, an increase in η from its benchmark value of 3.0 to its upper limit of 5.0 raises the predicted increase in output from 3.37 percent to 5.62 percent.

FIGURE 5
PREDICTED INCREASE IN E&S INVESTMENT
DUE TO 1 PERCENTAGE POINT INCREASE IN $ITCR^{E\&S}$
(for various values of tax competition slope (α)
and relative user cost elasticity (σ))



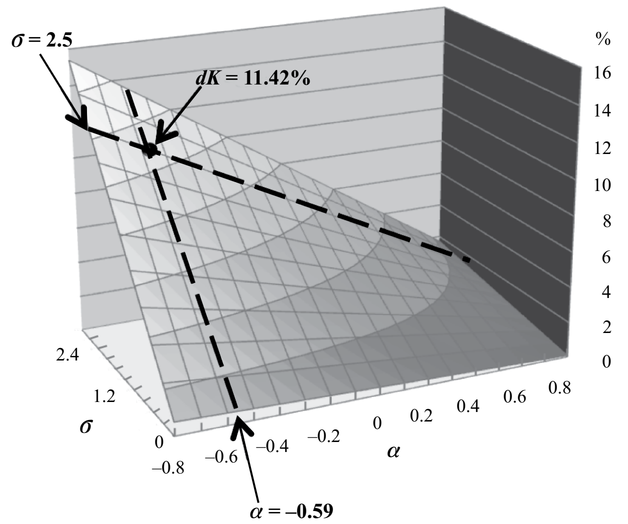
See notes to Figure 4.

FIGURE 6
PREDICTED DECREASE IN R&D INVESTMENT
DUE TO 1 PERCENTAGE POINT DROP IN *CITR*
(for various values of tax competition slope (α)
and relative user cost elasticity (σ))



See notes to Figure 4.

FIGURE 7
PREDICTED INCREASE IN R&D INVESTMENT
DUE TO 1 PERCENTAGE POINT INCREASE IN $ITCR^{R\&D}$
(for various values of tax competition slope (α)
and relative user cost elasticity (σ))



See notes to Figure 4.

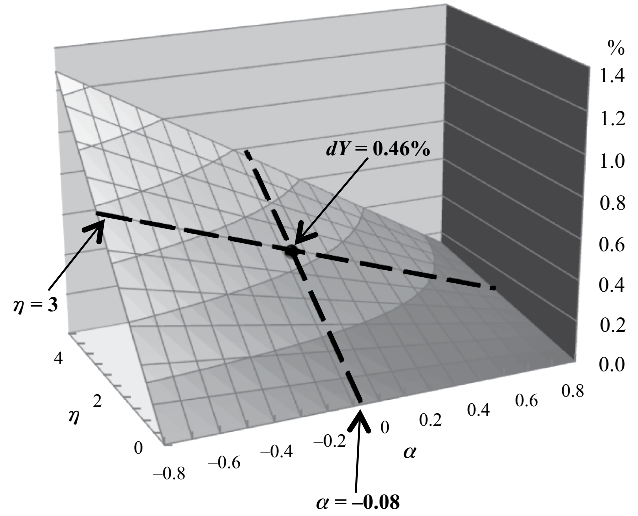
4.3. An Online Applet Allowing Users to Select Their Own Parameter Values

Figures 4 to 10 document the sensitivity of the simulations to the underlying parameter values. In order to allow users flexibility in tailoring the simulations to their own views on the appropriate parameter values best describing the firms operating in their states, we have created an applet that allows choices for the following parameters: σ, α, η, Λ, $\omega^{E\&S}$, and $\omega^{R\&D}$. The applet also allows users to choose the size of the increase or decrease in any one of the three tax policies. This could be quite valuable for policymakers or analysts debating the merits of a particular tax policy change under legislative consideration. Table 1 suggests what we believe is a plausible range of values, though any values can be employed in the user-directed simulations. The applet can be accessed at http://www.frbsf.org/csip/taxapp.php.

5. Summary

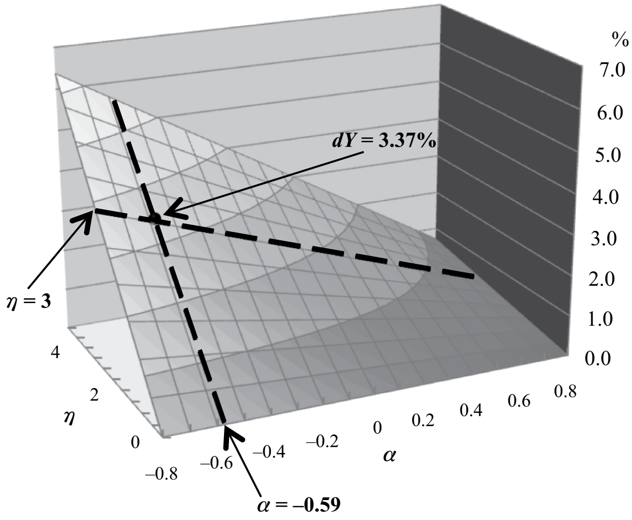
This article has developed a framework for quantifying the impacts of state business tax policies. We examine three tax instruments: the corporate income tax, the investment tax credit on equipment and structures, and the investment tax credit on research and development. The links among tax policies, investment, and output depend on a set of channels determined by economic theory and a set of parameters whose values are drawn from empirical research. We have provided illustrative calculations based on our preferred parameter values. Recognizing the differences that exist about the values of key parameters, we discuss how the predicted economic effects of these tax policy changes vary depending on the choice of these parameters. In addition, we have developed and made available online a simple web tool that al-

Figure 8
Predicted Increase in Output due to
1 Percentage Point Drop in *CITR*
(for various values of tax competition slope (α)
and elasticity of demand (η))



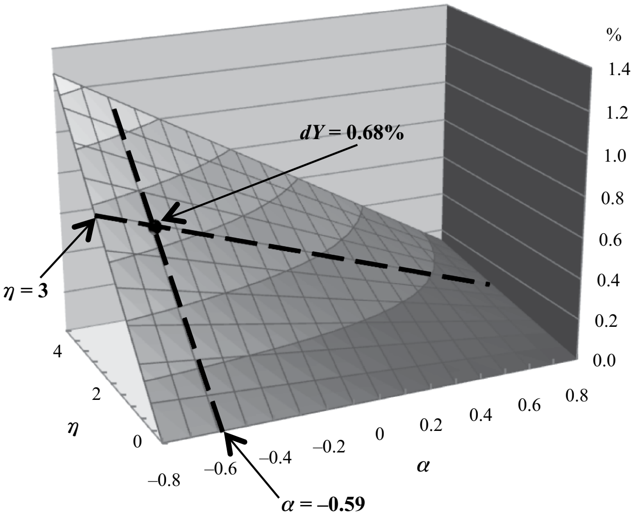
See notes to Figure 4.

Figure 9
Predicted Increase in Output due to
1 Percentage Point Increase in $ITCR^{E\&S}$
(for various values of tax competition slope (α)
and elasticity of demand (η))



See notes to Figure 4.

Figure 10
Predicted Increase in Output due to
1 Percentage Point Increase in $ITCR^{R\&D}$
(for various values of tax competition slope (α)
and elasticity of demand (η))



See notes to Figure 4.

lows users to insert their own preferred parameter values and simulate the economic effects for the state and tax policy of their choosing.

Three caveats should be kept in mind with our simulations. A comprehensive evaluation of a proposed tax policy requires several pieces of information. The simulation results presented in this article provide information on one important benefit. Additional information is required concerning the revenues that are decreased initially due to the tax incentives and increased eventually due to higher levels of economic activity. Moreover, second-round effects need to be considered. For example, generous investment incentives may require state governments to lower expenditures on government services or may induce firms to lower employment. That these effects are *second* does not necessarily imply that they are *secondary*. Nonetheless, our simulation results provide a valuable input to the complex process of policy evaluation.

A second caveat is that we have restricted ourselves to a limited number of fiscal options. Apart from the three state business taxes considered in this article, state policymakers have many other revenue options, such as sales taxes and user fees, as well as expenditure reductions. Job tax credits are an additional policy option that have been adopted by approximately half of states sometime during this decade. Given the sharp decrease in employment during the recent recession and the anemic pace at which jobs are recovering, job tax credits have received more attention as a policy tool. The framework developed in this article can be extended to consider the effects of job credits and other policies on employment.

Finally, since our simulations are at the state level, these results may not inform national policy. The calculations reported in this article only pertain to each state's investment and output from a change in its tax policy. Given the mobility of capital across and tax competition among states, a tax policy that looks highly desirable from the perspective of a single state may be much less desirable nationally. Increases in investment and output may be at the expense of other states. From a national perspective, state tax initiatives may well be a zero-sum game.[15] Simulating the impacts of a given state's policy on the behavior of other states and on national investment and output as a whole is beyond the scope of this article and our existing work, but it is a topic for future research.

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[15] In our analysis of equipment and structure capital formation, we could not reject the hypothesis that state business tax policy is a zero-sum game (Chirinko and Wilson 2008). Wilson (2009) finds a similar result for research and development.

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