

A Plucking Model of Business Cycles

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Abstract

The dynamics of unemployment fit what Milton Friedman labeled a plucking model: a rise in unemployment is followed by a fall of similar amplitude, but the amplitude of the rise does not depend on the previous fall. We develop a microfounded plucking model of the business cycle to account for these phenomena. The model features downward nominal wage rigidity within an explicit search model of the labor market. Our search framework implies that downward nominal wage rigidity is fully consistent with optimizing behavior and equilibrium. We reassess the costs of business cycle fluctuations through the lens of the plucking model. Contrary to New-Keynesian models where fluctuations are cycles around an average natural rate, the plucking model generates fluctuations that are gaps below potential (as in Old-Keynesian models). In this model, business cycle fluctuations raise not only the volatility but also the average level of unemployment, and stabilization policy can reduce the average level of unemployment and therefore yield sizable welfare benefits.

Keywords: Downward Nominal Rigidity, Stabilization Policy, Labor Search.

JEL Classification: E24, E30, E52

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1 Introduction

The unemployment rate in the United States displays a striking asymmetry: much of the time, it hovers around 5%, but occasionally it rises far above this level, peaking each time at a different maximum. Milton Friedman proposed a “plucking model” analogy to describe this behavior of the economy: “In this analogy, ... output is viewed as bumping along the ceiling of maximum feasible output except that every now and then it is plucked down by a cyclical contraction” (Friedman, 1964, 1993). Friedman highlighted one manifestation of these asymmetric dynamics: economic contractions are followed by expansions of a similar amplitude—as if the economy is recovering back to its maximum level—while the amplitude of expansions are not related to the previous contractions—each pluck seems to be a new event.

Workhorse models of the business cycle do not capture this asymmetry in unemployment and output. Instead, they see the business cycle as symmetric ups and downs of unemployment and output around an average level. An important implication of this view is that stabilization policy cannot affect the average level of output or unemployment. At best, stabilization policy can reduce inefficient fluctuations. As a consequence, in these models the welfare gains of stabilization policy are trivial (Lucas, 1987, 2003).

Friedman’s plucking model view of the business cycle potentially has very different implications for the welfare gains from stabilization policy. In this view, economic contractions involve drops below the economy’s full-potential “ceiling,” rather than symmetric cycles around a “natural rate.” Eliminating such drops increases average output and decreases average unemployment, which raises welfare by non-trivial amounts (De Long and Summers, 1988).

We develop this thesis by building a plucking model of the business cycle. The key ingredient for generating the plucking property in our model is downward nominal wage rigidity. We depart from the previous literature by introducing downward nominal wage rigidity within an explicit search model of the labor market. The search framework rationalizes unemployment as an equilibrium phenomenon and, most importantly, makes the downward rigidity of wages fully consistent with optimizing behavior, and thus robust to Barro’s (1977) critique that wage rigidity should neither interfere with the efficient formation of employment matches nor lead to inefficient job separations.

Our plucking model captures the pronounced asymmetry of the distribution of unemployment. Empirically the distribution of unemployment has a longer right tail than left tail. The

unemployment rate spends much time around 5%. Occasionally, it rises to levels much higher than this. In contrast, it never falls much below this level. Our plucking model generates this type of asymmetry in sharp contrast with standard models of unemployment dynamics.

In our plucking model, unemployment always lies above its no-shock steady-state level. Fluctuations in unemployment are shocks (plucks) away from this steady-state level and subsequent drifts back toward this level. This property is what allows the model to match the asymmetry in the distribution of the unemployment rate. This also shows that the natural-rate view of business cycles—and its corollary that stabilization policy can't effect mean output and unemployment—is not a necessary implication of imposing the discipline of optimizing behavior, equilibrium analysis, and rational expectations.

Intuitively, the distribution of unemployment is right-skewed in our model because good shocks mostly lead to increases in wages, while bad shocks mostly lead to increases in unemployment. The source of this asymmetry is our assumption of downward nominal wage rigidity. This notion has a long history within macroeconomics going back at least to Tobin (1972). The main theoretical challenge for this line of thinking has been how to justify the notion that wages don't fall in recessions despite obvious incentives of unemployed workers to bid wages down.

To make downward nominal wage rigidity robust to this critique, we build on the recent insights from the labor search literature. Hall (2005) pointed out that, once a search and matching model is purged of its ad hoc assumption of Nash-bargaining, wages are not uniquely pinned down. They are only constrained to lie within a wage-band, making some amount of wage-rigidity consistent with individual rationality and equilibrium. Intuitively, because of search frictions, unemployed workers cannot freely meet with firms and offer to replace employed workers at a lower wage. Instead, unemployed workers and potential employers must engage in a costly matching process. But after the worker and employer have matched, the worker has some monopoly power and therefore no longer has any reason to bid the wage down. As a result the wage has no reason to be driven to market-clearing level.

The plucking nature of our model has important normative implications. Reductions in the volatility of shocks not only reduces the volatility of the unemployment rate, but also reduces its average level. Eliminating all shocks in our model reduces the average unemployment rate from 5.8% to 4.2%. The welfare benefits of stabilization policy are therefore more than an order of magnitude larger in our model than in standard models in which stabilization policy cannot affect

the average level of output and unemployment.¹

In our model, a modest amount of inflation can “grease the wheels of the labor market” by allowing real wages to fall in response to adverse shocks even though nominal wages are downward rigid. Increasing the average inflation rate from 2% (our baseline calibration) to 4% yields a drop in average unemployment from 5.8% to 4.9%. The benefits of inflation diminish at higher levels of inflation but are quite large at low levels. Reducing the average inflation rate from 2% to 1% increases the average unemployment rate from 5.8% to 7.2%.

Our work is related to several strands of existing literature. Kim and Ruge-Murcia (2009, 2011) and Benigno and Ricci (2011) assume downward nominal wage rigidity in models where employment is restricted to fluctuate at the intensive margin only, i.e., they dispense with unemployed workers altogether. Akerlof, Dickens, and Perry (1996) and Schmitt-Grohe and Uribe (2016) close the labor market through some variant of the short-side rule, assuming the labor-market is demand-constrained when wages need to fall, but without explaining explicitly why unemployed workers do not bid down the wage of employed workers.

Our assumption of downward nominal wage rigidity is motivated by the microdata evidence on the existence of asymmetric wage adjustments. Micro-data panel studies of downward nominal wage rigidity, starting with McLaughlin (1994), Kahn (1997) and Card and Hyslop (1997), and more recently Barattieri, Basu, and Gottschalk (2014), point at a spike at zero in the density of nominal wage changes, strongly suggestive of downward nominal rigidity. As emphasized in Pissarides (2009) and Haefke, Sonntag, and van Rens (2013), only the existence of wage-rigidity for new hires has allocative implications. Haefke, Sonntag, and van Rens (2013) argue that wages of new hired are less rigid than those of existing workers. Gertler and Trigari (2009) argue that this result may be mainly due to a compositional effect. Bewley (1999, ch. 9) gives evidence that employers report a constraint to maintain internal equity between similar workers within the firm and therefore to tie the wage of new hires to the wage of older workers in the firm.

Recent work has explored several ways in which Lucas’ (1987, 2003) calculations may underestimate the costs of business cycle fluctuations and therefore the potential benefits of stabilization policy. Fluctuations are more costly when output is difference stationary (Obstfeld, 1994) and when shocks have fat tails (Barro, 2009). Uninsurable income risk also increases the cost of fluctuations (Krebs, 2007, Krusell et al., 2009). Our work highlights the notion that fluctuations may be

¹Recall that Lucas (2003) shows that the consumption equivalent welfare loss of business cycle fluctuations in consumption over the period 1947-2001 is 0.05% if consumers are assumed to have log-utility and face trend stationary fluctuations in output with normally distributed innovations.

more costly than Lucas estimates because they reduce the average level of output.

The paper proceeds as follows. Section 2 presents empirical evidence. Section 3 lays out our plucking model of business cycles. Section 4 describes the model's implications for the distribution of the unemployment rate. Section 5 shows that fluctuations increase the average level of unemployment and higher inflation reduces the average level of unemployment. Section 6 concludes.

2 Empirical Evidence

This section documents three salient asymmetries in the dynamics of the US unemployment rate over the post-WWII period: 1) Friedman's plucking property: the amplitude of a contraction forecasts the amplitude of the subsequent expansion, while the amplitude of an expansion does not forecast the amplitude of the subsequent contraction; 2) the distribution of the unemployment rate is right-skewed; and 3) the unemployment rate rises more quickly than it falls. In addition to this, we highlight the long duration of expansions in the data.

2.1 Defining Expansions and Contractions

The data that we use are the seasonally adjusted monthly unemployment rate for workers over 16 years old. Our sample period is January 1948 to February 2017. We define a business cycle peak as a month in which the unemployment rate is strictly lower than any month in the two years before, and weakly lower than any month in the two years after. We define business cycle troughs analogously. Notice that a business cycle peak is a trough in the unemployment rate and vice-versa. In what follows, a peak will always refer to a business cycle peak as opposed to a peak in the unemployment rate.

Figure 1 plots the unemployment rate over our sample period with vertical lines indicating the times that we identify as business cycle peaks and troughs. The algorithm described above identifies nine peaks and ten troughs. To this we add a peak at the start of our sample in January 1948 and at the end of our sample in February 2017. For comparison, the Business Cycle Dating Committee of the National Bureau of Economic Research (NBER) identifies a peak in November 1948.

Table 1 presents the peak and trough dates we identify. We also present the peaks and troughs identified by the NBER Business Cycle Dating Committee. The NBER peaks and troughs are

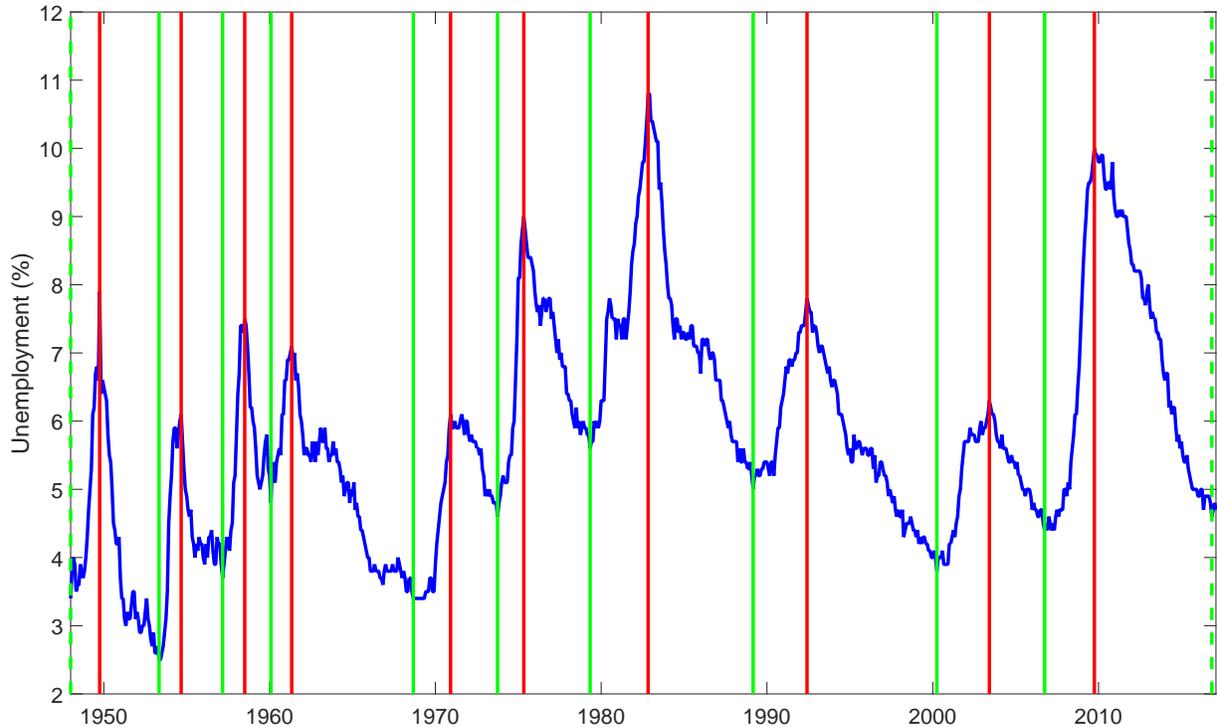


Figure 1: Peaks and Troughs in the Unemployment Rate

Note: The unemployment rate is plotted in blue. Business cycle peaks are denoted by green vertical lines, while business cycle troughs are denoted by red vertical lines.

based on a broader set of business-cycle indicators than only the unemployment rate. However, the times of peaks and troughs that we identify based solely on the unemployment rate are in most cases quite similar to the times identified by the NBER. The NBER peaks tend to lag our peaks by a few months and the NBER trough tend to proceed our troughs by a few months. This implies that our estimate of the average duration of contractions is about one year longer than what results from the NBER's dating procedure. In addition to this, the NBER identified a brief expansion period in 1980, which our procedure does not identify.

2.2 The Plucking Property

Figure 2 presents scatter plots illustrating the plucking property of the unemployment rate. The left panel plots the amplitude of an expansion against the amplitude of the previous contraction. The amplitude of expansions is defined as the percentage point decrease in the unemployment rate from the business cycle trough to the next peak. The amplitude of contractions is defined analogously. There is clearly a strong positive relationship between the amplitude of an expansion and the amplitude of the previous contraction in our sample period. In other words, the size of

Table 1: Business Cycle Peaks and Troughs

	Unemployment		NBER	
	Peak	Trough	Peak	Trough
1	[1/1948]	10/1949	11/1948	10/1949
2	5/1953	9/1954	7/1953	5/1954
3	3/1957	7/1958	8/1957	4/1958
4	2/1960	5/1961	4/1960	2/1961
5	9/1968	12/1970	12/1969	11/1970
6	10/1973	5/1975	11/1973	3/1975
7a	5/1979		1/1980	7/1980
7b		11/1982	7/1981	11/1982
8	3/1989	6/1992	7/1990	3/1991
9	4/2000	6/2003	3/2001	11/2001
10	10/2006	10/2009	12/2007	6/2009
11	[10/2016]			

Notes: Business cycle peaks and troughs defined solely based on the unemployment rate and, for comparison, business cycle peaks and troughs as defined by the Business Cycle Dating Committee of the National Bureau of Economic Research.

a contraction strongly forecasts the size of the subsequent expansion. We have included an OLS regression line in the panel. Table 2 reports the regression coefficient from this regression. The relationship is roughly one-for-one. For every percentage point increase in the amplitude of a contraction, the amplitude of the subsequent expansion increases by 0.96 percentage points on average. Despite the small number of data points, the relationship is highly statistically significant (t-statistic of 3.0).

The right panel plots the amplitude of a contraction against the amplitude of the previous expansion. In sharp contrast to the left panel, there is no relationship in this case. The size of an expansion does not forecast the size of the next contraction. In Friedman’s language, each contractionary pluck that the economy experiences is independent of the one before. The linear regression line in the panel is actually slightly downward sloping. But the association is far from statistically significant.

Overall, the two panels in Figure 2 strongly indicate that Milton Friedman was right: The amplitude of contractions forecast the amplitude of the subsequent contractions, but the amplitude of expansions don’t forecast the amplitude of the subsequent expansion.

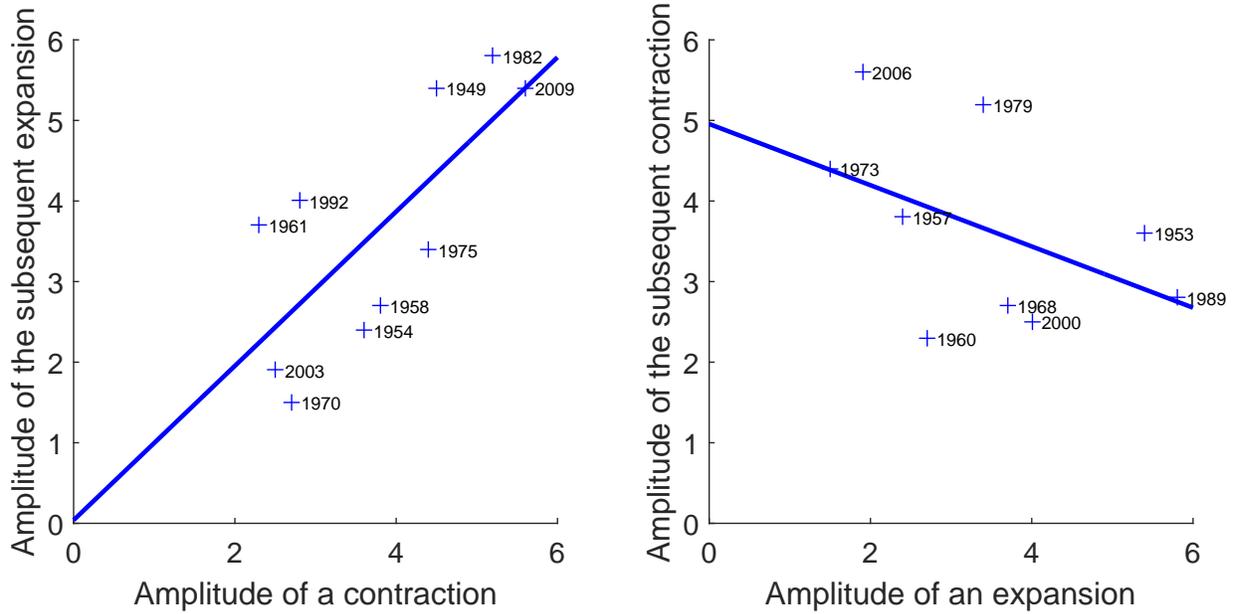


Figure 2: The Plucking Property of the Unemployment Rate

Note: OLS regression lines are plotted in each panel.

2.3 Skewness of Unemployment

Figure 3 plots a histogram of the distribution of the unemployment rate over our sample period. The unemployment rate is noticeably right skewed. Much of the mass of the distribution is close to 5% (median of 5.6% and mean of 5.8%). However, the right tail reaches quite a bit further out than the left tail. The minimum value of the unemployment rate in our sample is 2.5% in 1953. The maximum value is 10.8% in 1982. The maximum value is 5.2% above the median, while the minimum value is only 3.1% below the medium value. The skewness of the distribution is 0.60.

Table 2: Plucking Property of Unemployment

	β	R^2
Expansion on previous contraction	0.96 (0.32)	0.53
Contraction on previous expansion	-0.38 (0.27)	0.22

Notes: The first row reports the coefficient in an OLS regression of the size of an expansion (percentage point fall in unemployment rate) on the size of the previous contraction (percentage point increase in unemployment rate). The second row reports the coefficient in an analogous regression of the size of a contraction on the size of the previous expansion.

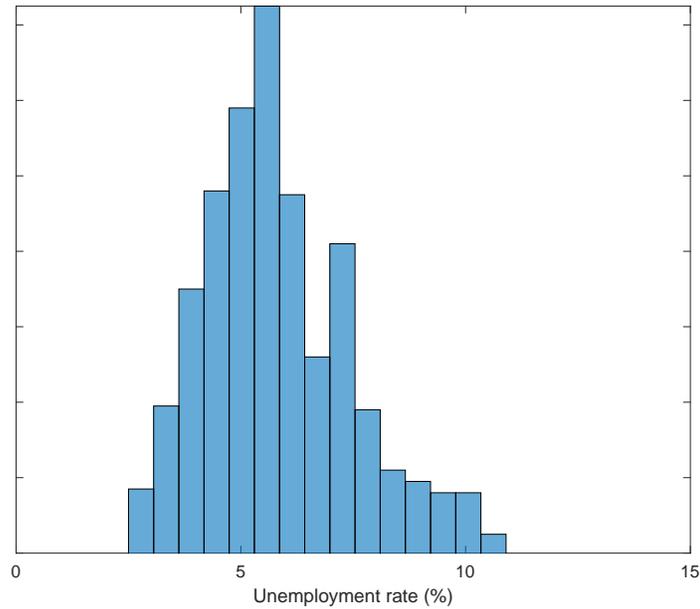


Figure 3: Distribution of Unemployment

2.4 Speed of Expansions Versus Contractions

A quite distinct form of asymmetry in the unemployment rate is that the unemployment rate rises much more quickly during contractions than it falls during expansions. A particularly simple way to illustrate this is to calculate the average speed of expansions and contractions in percentage points of unemployment per year. Table 3 reports two sets of estimates of the average speed of expansions and contractions. The first set weights expansions and contractions by their length, while the second set weights all expansions and contractions equally. (See the table note for details.) We find that the unemployment rate rises roughly twice as quickly during contractions (1.7 percentage points per year) than it falls during expansions (0.8 percentage points per year). This difference is highly statistically significant. We run a regression of the absolute value of the speed of expansions and contractions on a dummy variable for a spell being a contraction and find that the p-value for the dummy is 0.002.

2.5 The Duration of Expansions and Contractions

The final fact about the dynamics of the unemployment rate that we would like to highlight is the long duration of expansions and contractions. Looking back at Figure 1, we can clearly see that when the unemployment rate starts falling, it usually falls steadily for a long time. Table 4 lists

Table 3: Speed of Expansions Versus Recoveries

	Year Weighted	Spell Weighted
Speed of expansions	0.78	0.88
Speed of contractions	1.67	1.89
P-value for equal speed		0.002

Notes: The speed of expansion and contractions is measured in percentage points of unemployment per year. For each expansion and contraction, we calculate the change in unemployment over the spell and the length of time the spell lasts for. We then calculate the speed of expansions and contractions in two ways: 1) First calculate the speed in each spell and then take a simple average across spells. We refer to this as spell weighting. 2) Sum the change in unemployment across spells and sum the length of time across spells and then calculate the average speed by dividing the aggregate change in unemployment by the aggregate length of time. We refer to this as year weighting. We also regress the absolute value of the speed of adjustment for both expansions and contractions on a dummy for contractions and report the p-value for this dummy.

the duration of all expansions and contractions over our sample period. The average length of expansions is 55.6 months, or over four and a half years. Contractions are also quite persistent. The average length of contractions in our sample is 26.9 months. Perhaps most strikingly, in a few cases—the 1960s, 1980s, 1990s, and the current expansion—the unemployment rate has fallen steadily for six to eight years without reversal. We will argue that these long and steady expansions place interesting restrictions on the types of models or stock processes that drive business cycles.

Table 4: The Duration of Expansions and Contractions

	Dates		Length in Months	
	Peak	Trough	Expansion	Contraction
1	[1/1948]	10/1949		21
2	5/1953	9/1954	43	16
3	3/1957	7/1958	30	16
4	2/1960	5/1961	19	15
5	9/1968	12/1970	88	27
6	10/1973	5/1975	34	19
7	5/1979	11/1982	48	42
8	3/1989	6/1992	76	39
9	4/2000	6/2003	94	38
10	10/2006	10/2009	40	36
11	[10/2016]		84	
Mean			55.6	26.9

3 An Equilibrium Model of Downward Nominal Wage Rigidity

Households supply an exogenous quantity of labor—which we normalize to 1—to firms, from which firms produce a homogeneous good using the decreasing returns to scale technology:

$$Y_t = Z_t F(N_t), \tag{1}$$

where Y_t is output, N_t is employment, and Z_t is an exogenous productivity shifter, meant to capture any (non-modeled) change in labor productivity. Firms sell the good back to households in competitive markets at price P_t . (Because the goods market is competitive, the production side can equivalently be seen as consisting of a representative firm.) We focus the model on the functioning of the labor market. Because of search frictions, not all households are employed: workers are divided between employed N_t and unemployed $U_t = 1 - N_t$. Employed workers earn the nominal wage W_t , while unemployed earn nothing. We note $w_t = W_t/P_t$ the real wage.

Because we abstract from the intensive-margin labor-supply decision of households, households play an essentially passive role: they work, or at least try to, whatever the wage, and for this reason our assumption of no unemployment benefits has no consequences on the determination of employment. Since there is no capital accumulation, households' consumption/savings decisions do not matter much for the determination of aggregate variables either. Nevertheless, because the firm's hiring decision will be intertemporal, households do matter to determine the stochastic discount factor. We assume the stochastic discount factor between t and $t + s$ takes the standard form $Q_{t,t+s} = \beta^s u'(C_{t+s})/u'(C_t)$, where β is the discount factor and C_t is aggregate consumption at t . Thus, implicitly, we assume a representative agent with standard intertemporal separable preferences, which can be justified despite the heterogeneity in incomes by the existence of complete markets, or the assumption that households meet at the end of each period to share their incomes.

3.1 Labor-Demand

We first derive firms' demand for labor. Hiring workers is subject to hiring costs that take the form of search costs: with cost $Z_t c$ —proportional to productivity—a firm can post a vacancy, which will translate into a hire if the job offer matches a job seeker. A match happens with probability q_t , which a firm takes as given and the determination of which is described below. We assume that each firm is big enough so that it can abstract from the randomness in seeking a worker: hiring

one worker requires to post $1/q_t$ vacancy and has the certain cost $\frac{Z_t c}{q_t}$. Hiring costs are in terms of the same composite final good as the household consumes, and thus have price P_t . Besides, each period a fraction $s \in (0, 1)$ of a firm's workforce leaves the firm for exogenous reasons. Noting H_t the number of hires at t , a firm's workforce therefore evolves according to:

$$N_t = (1 - s)N_{t-1} + H_t. \quad (2)$$

(This assumes that workers hired at t start to work for the firm at t .)

A firm's real profits at t are real revenues $Z_t F(N_t)$, minus real labor costs $w_t N_t$, minus real hiring costs $\frac{Z_t c}{q_t} H_t I_{H_t \geq 0}$. A firm chooses employment and hires in order to maximize intertemporal real profits, discounting them using the representative household's discount factor, and subject to the flow equation (2). If firms hire every period, which we will impose in equilibrium, firms' labor-demand (equivalently hiring decision) is characterized by the first-order condition:

$$Z_t F'(N_t) = w_t + \frac{c Z_t}{q_t} - (1 - s) E_t \left(Q_{t,t+1} \frac{c Z_{t+1}}{q_{t+1}} \right), \quad (3)$$

which equates the marginal productivity of a worker to its cost to the firm, itself equal to the wage, plus the hiring cost, minus the expected savings of having a worker next period without having to hire him next period. For firms not to be willing to fire workers in equilibrium, it must be that the value of an (already hired) worker is positive. This imposes the following upper-bound on the wage:

$$w_t \leq Z_t F'(N_t) + (1 - s) E_t \left(Q_{t,t+1} \frac{c Z_{t+1}}{q_{t+1}} \right), \quad (4)$$

The probability of filling a vacancy q_t is determined in equilibrium through an exogenous matching function $q(\cdot)$ of the tightness ratio θ_t , the ratio of the number of vacancy posted $\frac{H_t}{q_t}$ to the number S_t of job-seekers at the beginning of the period: $\theta_t = H_t / (q_t S_t)$. The probability for an unemployed worker to find a job is equal to the ratio of hires to job-seekers $f(\theta_t) \equiv H_t / S_t = \theta_t q(\theta_t)$. We assume that a worker losing his job between periods $t - 1$ and t gets a chance to find a new job at the beginning of period t and therefore to work in period t , spending no period without a job. Thus, the number of job-seekers at t is $S_t = 1 - (1 - s)N_{t-1}$.² The employment flow equation (2) can therefore be rewritten using the tightness ratio θ_t instead of hires H_t :

$$N_t = 1 - (1 - f(\theta_t)) [1 - (1 - s)N_{t-1}] \quad (5)$$

²The number S_t of job seekers at t , although it can be seen as the number of unemployed at the beginning of the period t , is not equal to what we defined as the unemployment rate U_t at t , which only counts those job seekers *who did not find a job at t* .

3.2 Wage-Setting

Because of search frictions, unemployed workers cannot instantly meet with firms to offer to replace employed workers at a lower wage. Instead, an unemployed worker always meets a firm after a match, at which point he no longer has any reason to bid the wage down. As a result the wage has no reason to be driven to market-clearing level, nor to be uniquely pinned down to any level: nothing forces the equilibrium to be at the crossing of the labor-demand curve (3) and labor supply curve $N_t = 1$. Instead, there are only upper and lower bounds on an equilibrium wage. The upper-bound is defined by the no-firing condition (4). Since we assume an exogenous, inelastic labor supply, there is no lower bound coming from workers' unwillingness to work for too low a wage. However, an equilibrium wage must prevent firms from being willing to hire more workers than the supply of them. Using the labor-demand (3), the condition of no excess labor demand $N_t \leq 1$ translates into the following lower-bound on the wage:

$$w_t \geq Z_t F'(1) - \frac{cZ_t}{q_t} + (1-s)E_t \left(Q_{t,t+1} \frac{cZ_{t+1}}{q_{t+1}} \right) \quad (6)$$

In-between these two bounds, all wages are consistent with individual optimality. This continuum of wages defines an infinity of equilibria, each characterized by an assumption on wage-setting. We consider three wage-setting assumptions: downward nominal wage rigidity, and two benchmarks: flexible wages and symmetric real wage rigidity.

Start with flexible wages. Following Blanchard and Gali (2010) and Michaillat (2012), we specify wage flexibility through the short-cut assumption that real wages follow productivity:

$$w_t = \bar{w}Z_t, \quad (7)$$

where \bar{w} is a constant. The short-cut is justified by the fact that this is a very close approximation to the dynamics of wages under the assumptions of either market-clearing or Nash-bargaining. However, as Shimer (2005) shows, the search framework with flexible wages fails to account for the fluctuations in the unemployment rate: when wages follow productivity, all the effect of shocks goes to prices, leaving quantities unchanged.

Our second benchmark is symmetric real wage rigidity, as considered in previous papers on wage rigidity in search models. Specifically, we assume that real wages adjust slowly to productivity by following Shimer (2010)'s specification of the real wage as a weighted average of the past real wage and present flexible wage:

$$w_t = \rho w_{t-1} + (1-\rho)\bar{w}Z_t, \quad (8)$$

where ρ is a weight between 0 and 1.

We contrast symmetric real wage rigidity with our main assumption of downward nominal wage rigidity. We assume that the nominal wage is set to the flexible wage, except if this requires the nominal wage to fall below a threshold defined as a fraction of the past nominal wage: $W_t = \max\{P_t \bar{w} Z_t, \gamma W_{t-1}\}$. The weight on the past wage $\gamma \in [0, 1]$ characterizes the extent of wage rigidity. Expressed in terms of real wages, and noting Π_t the inflation rate $\Pi_t = P_t/P_{t-1}$, the wage-setting equation becomes:

$$w_t = \max \left\{ \bar{w} Z_t, \gamma \frac{w_{t-1}}{\Pi_t} \right\}. \quad (9)$$

Downward nominal wage rigidity adds the lower-bound $\gamma w_{t-1}/\Pi_t$ on the present real wage.

The three specifications of wage-setting do not explicitly impose that the wage remains within the wage band defined by the no-firing condition (4) and no excess demand condition (6). However, we will check that they do in all our simulations.

3.3 Equilibrium

To close the model, we assume that the good market clears: production meets households' demand for consumption and firms' demand for hiring services:

$$Y_t = C_t + \frac{cZ_t}{q(\theta_t)} [N_t - (1-s)N_{t-1}], \quad (10)$$

An equilibrium is then, given an exogenous process for productivity (Z_t) and an initial condition for employment N_0 , processes for the six endogenous variables $N_t, C_t, Y_t, \theta_t, w_t, \Pi_t$ that satisfy the production function (1), the labor demand (3), the employment flow equation (5), the no-firing condition (4) and no-excess-demand condition (6), the good market-clearing condition (10), and the downward nominal wage rigidity wage-setting rule (9)—or the alternative benchmark (8). This only determines an equilibrium once monetary policy is specified. We assume that monetary policy sets the inflation rate to a constant target $\bar{\Pi}$ at all periods.

3.4 Productivity Growth

Productivity growth matters when considering downward nominal wage rigidity. In an economy with high trend growth, episodes where wages need to decrease are short-lived, as trend productivity soon brings the flexible wage back to previous levels. In contrast, in a low-growth economy, such episodes can have much more devastating consequences, as the downward nominal wage

rigidity constraint can be binding for much longer. We thus allow for the possibility of trend growth.

We consider a time-trend in productivity: we assume that productivity shocks Z_t are the sum of a deterministic trend at rate g , and an AR(1) process (A_t):

$$\ln(Z_t) = g \cdot t + \ln(A_t), \quad (11)$$

$$\ln(A_t) = \rho_a \ln(A_{t-1}) + \sigma_e^a \varepsilon_t^A, \quad (12)$$

where ε_t^A has mean zero and variance one. Accordingly, we detrend consumption, output and wages by defining $\tilde{C}_t \equiv \frac{C_t}{e^{gt}}$, $\tilde{Y}_t \equiv \frac{Y_t}{e^{gt}}$, and $\tilde{w}_t \equiv \frac{w_t}{e^{gt}}$, while N_t and θ_t are stationary and need no detrending.

3.5 Solution Method

Given the asymmetries and non-linearities our model is meant to capture, we rely on global methods to numerically solve for the equilibrium. A solution to the model can be described as policy functions for the 5 variables C, θ, N, Y , and w as a function of a 3-variable state: the exogenous state of productivity A , and the endogeneous states of lagged employment N_{-1} and lagged wage w_{-1} . We form a discrete grid of the state-space, approximate the stochastic processes for the exogenous productivity variable using the Tauchen method, and solve the model by iteration on the policy functions. Details are provided in appendix A.

An issue arises in solving the model: on a grid of the state (A, N_{-1}, w_{-1}) , some points of the grid necessarily feature high lagged wages and low productivity. As soon as the calibrated value of γ is high enough (and inflation low enough) so that the downward-rigidity constraint on wages has some bite, some of these states will have firms willing to fire workers, violating the no-firing condition. However this is not to say that the no-firing constraint is likely to be violated on an equilibrium path: these states are very unlikely to occur—we check ex post that our simulated paths remain well away from these states. Solving the equilibrium in these unlikely extreme states is nevertheless necessary to calculate expectations in states that do occur with reasonable probability on an equilibrium path. We adopt the following approach: in a state where the no-firing condition fails, we assume that firms are forbidden to fire workers and simply do not hire.³

³The symmetric problem may occur with the no-excess-demand condition under symmetric real wage rigidity: wages may be so much below productivity that firms are willing to hire more workers than there are. We deal with such cases in the same way: we assume that firms hire all workers but no more, and leave the wage at its value.

β	1-0.04/12
α	2/3
g	0
s	0.034
η	0.5
μ	1
c	0.150
\bar{w}	0.674 (DNWR) 0.678 (SRWR)

Table 5: Calibration: steady-state parameters.

3.6 Calibration

We calibrate the model to a monthly frequency. We assume a CRRA utility $u'(C) = C^{-\sigma}$, a Cobb-Douglas production function $F(N) = N^\alpha$, and a Cobb-Douglas matching function $q(\theta) = \mu\theta^{-\eta}$. Start with the parameters that determine the steady-state of the model. For preferences, we calibrate the household's discount factor β to correspond to an annual risk-free interest rate of 4%, and we assume utility to be logarithmic in consumption: $\sigma = 1$. For production, we set decreasing returns to $\alpha = 2/3$ to get the standard labor share. We consider the case of no growth $g = 0$. We set the separation rate to the average $s = 3.4\%$ per month reported by Shimer (2005). We set the elasticity of the matching function to $\eta = 0.5$, in the middle of the range reported in Petrongolo and Pissarides (2001)'s survey. The parameters μ and c jointly determined hiring costs. One of the two is redundant: only $c\mu^{\frac{-1}{1-\eta}}$ is identified—details are provided in appendix B. We normalize μ to 1. We set c so that steady-state hiring costs c/q are 10% of the monthly steady-state wage \bar{w} , in line with what Jose and Manuel (2009) report based on the Employer Opportunity Pilot Project survey in the US. We set the last parameter, the steady-state wage \bar{w} , to target the average level of unemployment over the period 1964-2009: 5.8%. In the benchmark of symmetric real wage rigidity, the steady-state is equal to the average. In the case of downward nominal wage rigidity, targeting the average of 5.8% sets the steady-set level to 4.2%. Table 5 sums it all up.

The other parameters only affect the dynamics of the economy: the parameters of the productivity process govern the shocks that hit the economy while the parameters of wage rigidity govern the responsiveness of the economy to these shocks. We assume the innovations ε_t^a are normal and calibrate $\rho_a = 0.98$ and $\sigma_\varepsilon^a = 0.005$, following Shimer (2010). Finally, we calibrate wage rigidity. We set $\gamma = 1$ (nominal wages cannot fall). We assume the inflation target $\bar{\Pi}$ is 2%

Shock process	ρ_a	0.98
	σ_e^a	0.005
Inflation target	$\bar{\Pi}$	1+0.02/12
Downward nominal wage rigidity	γ	1
Symmetric real wage rigidity	ρ	0.9

Table 6: Calibration: shock and wage-rigidity parameters.

annually. Table 6 sums it all up.

4 An Elastic String Glued Lightly to a Board

In this section, we consider the positive properties of our model. We check that individual incentives are never violated in our simulations, then contrast the properties of unemployment in the model with the natural-rate perspective, as illustrated by the benchmark of symmetric real wage rigidity. First, our model is a plucking model: unemployment always lies above its steady-state level, not around. Second, the model fits the asymmetric distribution of the unemployment rate in the data.

4.1 No Violation of Individual Optimality

First, we confirm that downward nominal wage rigidity does not conflict with individual rationality and equilibrium. We check that in our simulations, the no-firing constraint—and the constraint of no excess-demand of labor—is satisfied. Figure 4 illustrates this result (here in the case of a time trend) by plotting a simulated sample path of the wage under our main assumption of downward nominal wage rigidity, along with the upper and lower bound defining the wage band. The wage remains always well below the level at which workers would begin to cost more to firms than they bring in. Firms do not fire workers in downturns (or more exactly do not fire more than the exogenous destruction rate) and keep hiring, although less.

4.2 Around the Natural Rate Mean vs. Drops Below the Potential Ceiling

We turn to the properties of unemployment in our model. Figure plots a simulated unemployment rate series in the case of a time trend in productivity. We plot on the same graph the response of the unemployment rate to the same shocks under our main assumption of downward nominal wage

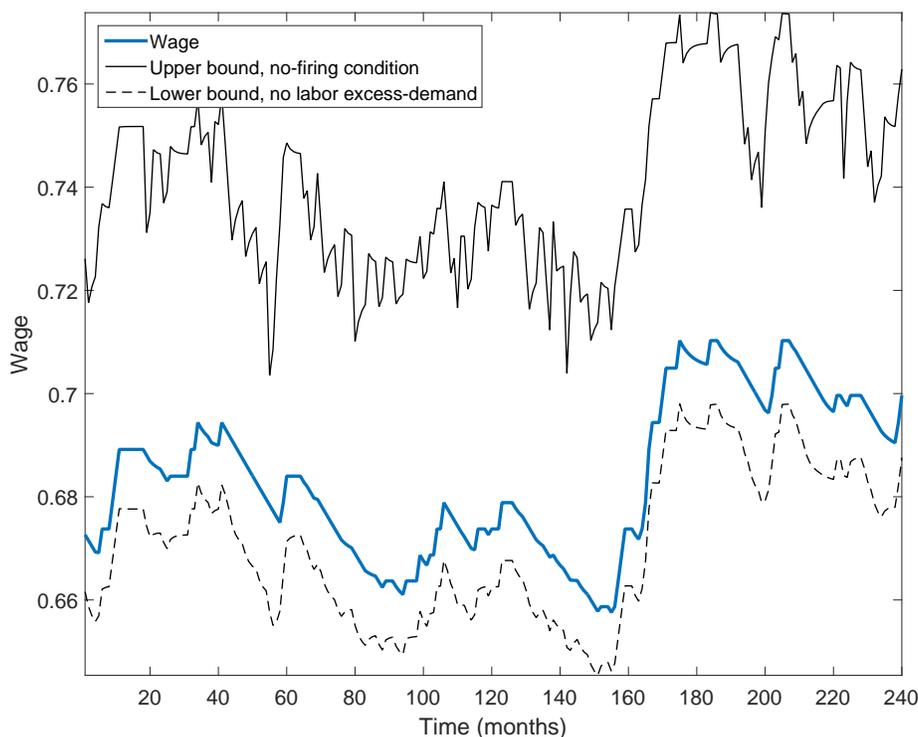


Figure 4: Simulated path for wages and the wage band under downward nominal wage rigidity.

rigidity, and in the benchmark of symmetric real wage rigidity. In addition, we superimpose the steady-state rates of unemployment—the rates that would prevailed absent any shock—under both assumptions. The figure illustrates the sharp contrast between two views of the business cycle.

In the benchmark of symmetric real-wage rigidity, unemployment fluctuates symmetrically above and below its steady-state level (set to 5.8%), which corresponds to its average. This steady-state average fits the most standard acceptations of the concept of a natural level of unemployment, which in this case can be equivalently defined as the long-run unemployment rate, the average unemployment rate, and the unemployment rate that would prevail absent any form of wage rigidity. (It is not the Non Accelerating-Inflation Rate of Unemployment (NAIRU) however—the unemployment rate consistent with a constant inflation rate—which is instead the red plain curve since money neutrality holds under symmetric real wage rigidity.)

In contrast, with downward nominal wage rigidity unemployment always lies above its steady-state level (set to 4.2%). Decreases in productivity increase unemployment above a lower bound of about 4.6%, while increases in productivity never decrease it below because wages adjust easily

upward when higher productivity shifts labor demand. The average unemployment rate is no longer the steady-state level of unemployment. Flipping the figure upside-down to go from the unemployment rate to output, the model sees business cycle fluctuations as, in the words of Milton Friedman, “an elastic string glued lightly to a board, and plucked at a number of points chosen more or less at random”. This view of business cycles is also the Old-Keynesian view, which is still present today as a vestige in the terminology of “potential output” and “output gap”—although “potential output” is now used as a synonym of “natural output”, and a “gap” is no longer meant to always be positive. Indeed, Okun (1962) defined potential output as the answer to the question: “how much output can the economy produce under condition of full employment?” Although he qualified that “the full employment goal must be understood as striving for maximum production without inflationary pressure; or, more precisely, as aiming for a point of balance between more output and greater stability, with appropriate regard for the social valuation of these two objectives.”, his use of the concept had little resemblance with either a natural rate or the NAIRU.

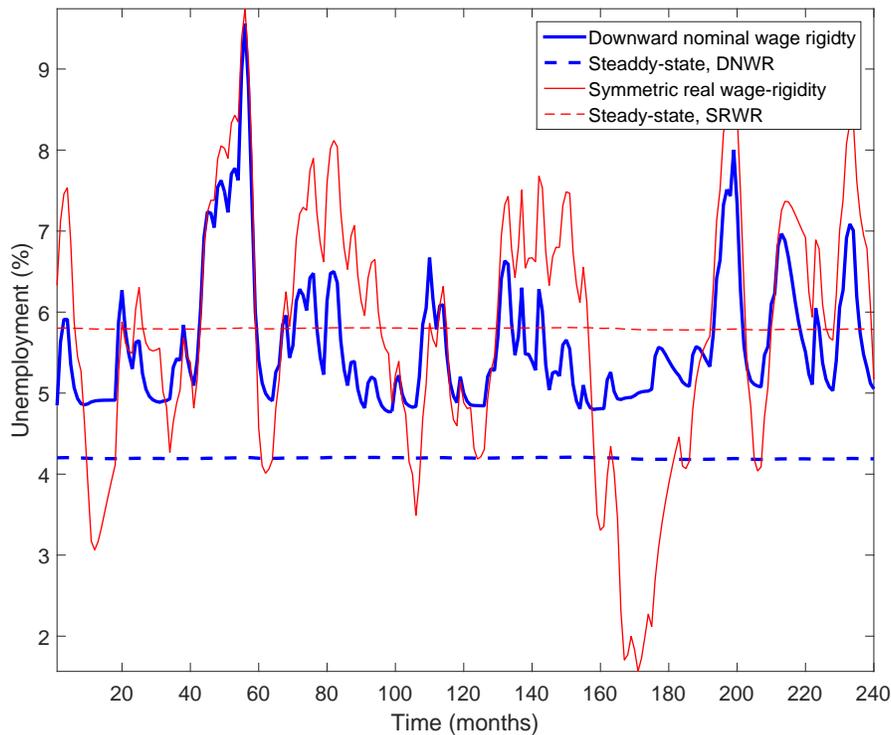


Figure 5: Simulated path for the unemployment rate. The blue curve is for the model under our main assumption of downward nominal wage rigidity; the red curve is for the benchmark of symmetric real wage rigidity. The shocks are the same in both cases.

4.3 Asymmetries

The natural-rate view and the plucking model differ as to where they locate the steady-state level of unemployment—unemployment absent any shock. Simply put, on the graph of the empirical unemployment rate, the natural view would draw the steady-state in the middle, while the plucking model would draw it below. Which is right? Is it possible to distinguish empirically between the plucking model and the natural-rate view? Such a test was the initial focus of Friedman (1964). Friedman pointed at one feature of the data that speaks in favor of the plucking model. Because in the plucking model contractions can be of various sizes but expansions are returns to the potential ceiling, the amplitude of an expansion should depend on the size of the previous contraction, but the amplitude of a contraction should not depend on the amplitude of the previous expansion. In contrast, no such correlation is predicted by the natural-rate model.

Another related distinction between the two models is their predictions for the distribution of the level of the unemployment rate. Again, the plucking model speaks in favor of an asymmetry: the distribution of the unemployment rate is skewed to the right, as the unemployment rate can reach high levels, but is bounded below. In contrast, in the natural-rate view, fluctuations are symmetric and this symmetry translates to the distribution of the unemployment rate: it is not skewed.

Figure 6 plots the histograms of the unemployment rate predicted by the plucking model with downward nominal wage rigidity, by the natural-rate model with symmetric real wage rigidity, and the empirical histogram of the civil unemployment rate among workers aged 15 to 64 from 1970 to 2015. The empirical distribution is right-skewed, although not as much as in our calibration of the plucking model.

5 Costs of Business Cycles and Benefits of Stabilization Policy

We now turn to the normative implications of our model. First, we reassess the costs of business cycle fluctuations through the lens of the plucking model. Second, we consider how monetary policy can achieve the benefits of stabilization implied by the model.

5.1 First-Order Effect of Economic Fluctuations

In a thought-provoking exercise, Lucas (1987, 2003) asked whether a reasonable estimate of the benefits of stabilization policies justifies the attention that their design receive. He answered neg-

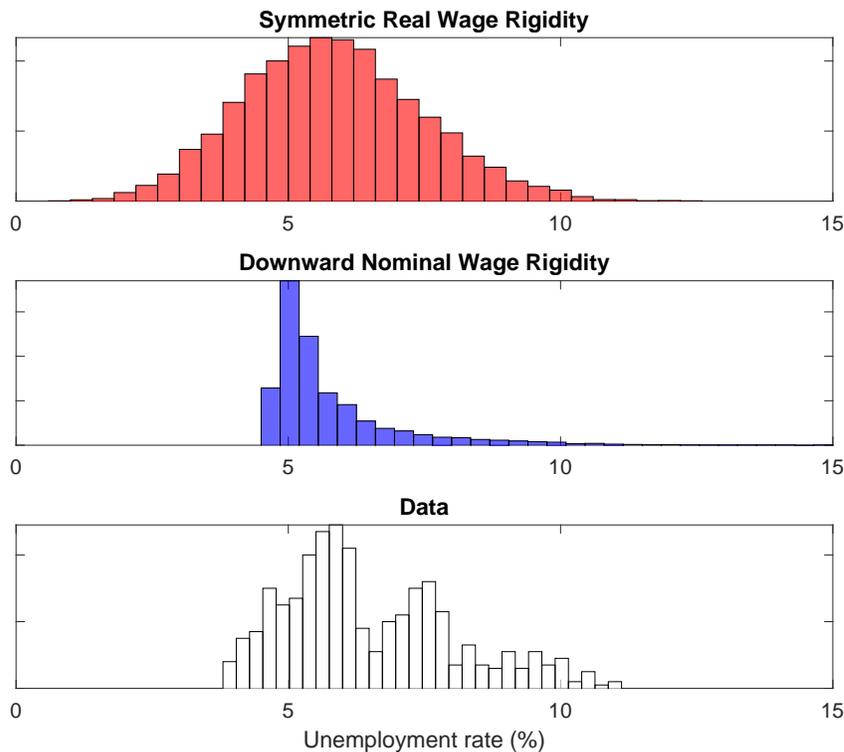


Figure 6: Distribution of the unemployment rate in the model with downward nominal wage rigidity, in the benchmark of symmetric real wage rigidity, and in the data.

atively: replacing the stochastic stream of consumption of a representative agent by a constant stream with the same mean would yield extremely small welfare gains, unlikely to compensate for the costs of stabilization.

Subsequent literature has considered whether Lucas’s result is robust to alternative assumptions on preferences toward risk (Obstfeld (1994), Dolmas (1998), Tallarini (2000)), or to removing the assumption of perfect insurance against idiosyncratic shocks induced by the existence of complete markets (Imrohoroglu (1989), Atkeson and Phelan (1994), Krussel and Smith (1999)). Most of these papers show that such extensions can beef up the costs of business cycles, and thus the benefits of stabilization policy. Yet, because Lucas’s initial estimate is so small, finding bigger estimates does not necessarily overcome the general conclusion that fluctuations don’t matter much: these papers still find small—although not as small as Lucas’s—costs of business cycle fluctuations.

The robustness of Lucas’s result is not necessarily surprising. The contrary intuition that stabilization policies can do much—the intuition that prevailed before Lucas’s at least—relies on the presumption that they can eliminate slumps, and can do so without getting rid of the boom:

that they affect not only the volatility, but also the mean level of unemployment and output. Because Lucas assumes away the possibility for policy to change the mean, there is nothing counter-intuitive or paradoxical in his result.

The question then is whether the assumption that stabilization policy can affect the mean is a reasonable assumption to entertain. We have shown that it is fully consistent with a commitment to methodological individualism, and with our current understanding of the reason for wage rigidity. In our model, replacing the process for productivity with a process with the same mean but no volatility—as in Lucas’s experiment—would decrease the unemployment rate. In our calibration, the decrease would be from an average 5.8% when inflation is targeted to be 2%, to the steady-state level of 4.2%.

5.2 Greasing the Wheels of the Labor Market

Lucas’s experiment of eliminating all fluctuations is meant to give an upper-bound of the benefits of stabilization policy, abstracting from the constraints that may exist on what outcomes policy can actually achieve. Our microfounded model permits to consider specific policies, and to not assume but derive their effects. In the rest of the paper, we consider one specific such policy: monetary policy. The reliance on monetary policy to alleviate the inefficiency created by downward nominal wage rigidity is as old as the early emphasis on downward nominal wage rigidity by Tobin (1972).

We consider the effect of a simple policy choice: the inflation target. Figure 7 plots the reaction of the unemployment rate to the same shocks, under different values for the inflation target, from 1% to 4%. A higher inflation target decreases the average unemployment rate by facilitating the adjustment of wages. Inflation allows real wages to adjust without touching to nominal wages, and as such alleviates the constraints of downward nominal wage rigidity. Inflation greases the wheels of the labor market.

In our calibration, increasing the inflation target from 2% to 4% decreases average unemployment from 5.8% to 4.9%. Decreasing the inflation target to 1% instead increases average unemployment to 7.2%.

6 Conclusion

We build a plucking model of the business cycle that captures the pronounced skewness of the unemployment rate. Unemployment arises from search frictions in the labor market and is skewed

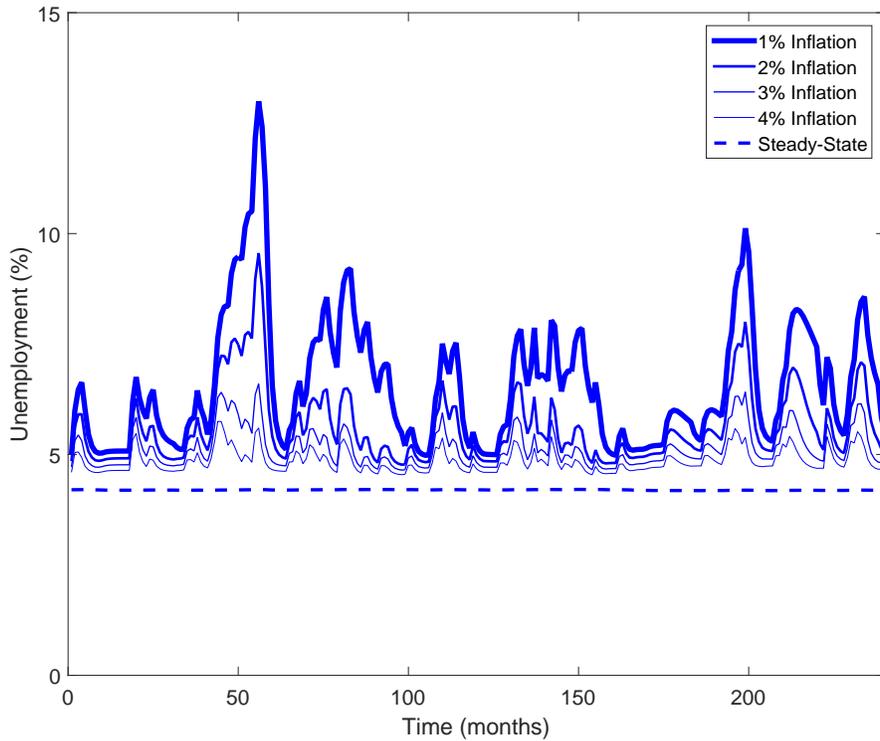


Figure 7: Simulated path for the unemployment rate for different levels of the inflation target. The shocks are the same in all cases.

due to downward nominal wage rigidity. In contrast to earlier models of downward nominal wage rigidity, our model is fully consistent with optimizing behavior and therefore robust to the Barro (1977) critique.

We show that in our model eliminating business cycles has large welfare benefits since it lowers the average unemployment rate. Our simulations imply that eliminating all fluctuations could lower the average unemployment rate by about 1.5 percentage points. Downward nominal wage rigidity provides one rationale for a positive inflation rate. Our results imply that moving from a 2% inflation target to a 4% inflation target would lower the average unemployment rate by roughly 1 percentage point, while lowering the inflation target to 1% would raise the average unemployment rate by about 1.5 percentage points.

A Solution Algorithm

We describe the details of our solving method, here in the case of our main assumption of downward nominal wage rigidity—the method is similar for symmetric real wage rigidity. Incorporating the assumptions of CARA preferences and Cobb-Douglas technology, and a monetary policy of constant inflation $\bar{\Pi}$, solving for the equilibrium consists, given the exogenous productivity perturbations $\ln(A_t)$ in solving for the 5 endogeneous variables—some of which have been detrended— $N_t, \tilde{C}_t, \tilde{Y}_t, \theta_t, \ln(\tilde{w}_t)$, defined by the five-equation system:

$$e^{\ln(A_t)} \alpha N_t^{\alpha-1} = e^{\ln(\tilde{w}_t)} + \frac{ce^{\ln(A_t)}}{q(\theta_t)} - (1-s)\beta \tilde{C}_t^\sigma E_t \left(\tilde{C}_{t+1}^{-\sigma} e^{(1-\sigma)g} \frac{ce^{\ln(A_{t+1})}}{q(\theta_{t+1})} \right), \quad (\text{A.1})$$

$$\tilde{w}_t = \max \left\{ \bar{w} e^{\ln(A_t)}, \frac{\gamma}{e^{g\bar{\Pi}}} \tilde{w}_{t-1} \right\}, \quad (\text{A.2})$$

$$1 - N_t = (1 - f(\theta_t)) [1 - (1-s)N_{t-1}], \quad (\text{A.3})$$

$$\tilde{Y}_t = e^{\ln(A_t)} F(N_t), \quad (\text{A.4})$$

$$\tilde{Y}_t = \tilde{C}_t + \frac{ce^{\ln(A_t)}}{q(\theta_t)} [N_t - (1-s)N_{t-1}]. \quad (\text{A.5})$$

A.1 Steady-State

A non-stochastic steady-state equilibrium with $A_t = 1$ is such that (N, θ) solve the two-equation system⁴:

$$\alpha N^{\alpha-1} = \bar{w} + \frac{c}{q(\theta)} [1 - \beta(1-s)e^{(1-\sigma)g}], \quad (\text{A.6})$$

$$f(\theta) = \frac{sN}{1 - (1-s)N}. \quad (\text{A.7})$$

Once N and θ are solved for, \tilde{Y} and \tilde{C} are given by:

$$\tilde{Y} = N^\alpha, \quad (\text{A.8})$$

$$\tilde{C} = \tilde{Y} - \frac{c}{q(\theta)} sN. \quad (\text{A.9})$$

A.2 Iteration Method

A solution to the model can be described as policy functions for the 5 variables \tilde{C}, θ (or equivalently and for convenience, $1/q$), N, \tilde{Y} , and $\ln(\tilde{w})$ as a function of the 3-variable state: the exogenous state of productivity $\ln(A)$, and the endogeneous states of lagged employment N_{-1} and

⁴For the downwardly-rigid nominal-wages equilibrium, we assume $\bar{\Pi}e^g \geq \gamma$ otherwise there is no steady-state equilibrium.

lagged wage w_{-1} . We form a discrete $21 \times 21 \times 21$ grid of the state-space, approximate the stochastic processes for the exogenous productivity variable using the Tauchen method, and solve for the policy functions at each point of the grid by policy function iteration. Specifically, we start from an initial guess on the policy functions C and $1/q$, and use this guess to calculate C_{t+1} and $1/q_{t+1}$, and from there the expectation term in equation (A.1). In calculating the expectation term, we need to evaluate the policy function at points that are not on the grid. We do so through linear interpolation. Given this expectation term, we solve for the equilibrium in this state of the grid—details are provided below—and store the solution for C and θ . Done in all states of the grid, this provides a new guess for the policy functions. We repeat until convergence of the policy functions.

A.3 Solving Within a Loop

At each iteration of the iterative algorithm, and at each point of the grid, we need to solve for the system (A.1)-(A.5), given the expectation term E_t^1 . To do so, we define a function of N in the following way:

- Through equation (A.3): $\theta(N)$.
- Through equation (A.4): $Y(N)$.
- Through equation (A.5): $C(N)$.
- Equation (A.1) is then an equation in N alone that can be solved for N . (We use the bisection method to do so.)

A.4 Dealing with the Constraints

A solution N to equation (A.1) needs to lie between $(1 - s)N_{t-1}$ and 1. Otherwise, the firm would need to fire people and the no-firing condition (4), or no excess-demand condition (6) would fail. In the unlikely states—which do not occur on the sample paths in our simulations—where the no-firing constraint fails, we assume that the firm does not hire nor fire workers and thus set $N_t = (1 - s)N_{t-1}$. In the unlikely states—which do not occur on the sample paths in our simulations—where the no-excess demand constraint fails, we assume that the firm hires all the available workers and thus set $N_t = 1$.

B Normalization of μ

We show that only the calibration of $c\mu^{\frac{-1}{1-\eta}}$ —not of μ and c separately—matters. The two parameters c and μ only show up as $c/q(\theta)$ and $f(\theta)$ in the system characterizing the equilibrium. Because $q = \mu^{\frac{1}{1-\eta}} f^{\frac{-\eta}{1-\eta}}$, we have that:

$$\frac{c}{q} = \left(c\mu^{\frac{-1}{1-\eta}} \right) f^{\frac{\eta}{1-\eta}}, \quad (\text{B.1})$$

so that only $c\mu^{\frac{-1}{1-\eta}}$ is identified. We thus normalize μ to one.

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