Monetary Policy and Skill Heterogeneity

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Abstract

College educated individuals have less volatile hours, but more volatile wages over the business cycle compared to individuals with less than a college education. Additionally, lower-skilled individuals reset their wages less frequently than higher-skilled individuals. Using this last fact, I build a business cycle model with price and differential nominal wage rigidities that captures the behavior of hours and wages observed in the data. I go onto consider the welfare consequences of different monetary policy rules and find that rules that are preferred by one skill group may not be preferred by the other one. Finally, I show that a simple, linear interest rate rule with optimally chosen coefficients comes close to matching the results from solving a full-fledged Ramsey problem.

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1 Introduction

Participants in the labor market are heterogeneous on a number of dimensions. Are some groups helped or harmed more than others if this heterogeneity is ignored in the formation of monetary policy? How, if at all, does heterogeneity change optimal monetary policy? In the workhorse model for monetary policy, the representative agent New Keynesian model, answering these questions is ruled out by assumption. Following a recent wave of research (see next section) which builds heterogeneity into these sorts of models, I introduce two types of workers distinguished by their skill status and frequency of nominal wage adjustment in a model similar to Erceg et al. (2000). Using a combination of micro and macro data in a calibration exercise, I show that the second moments of the simulated model come close to their counterparts in the data. I then use the model to address the policy questions.

In the model prices and wages are not adjusted every period. Firms and workers have some pricing power in setting their prices and wages, but face a constant probability of not being able to adjust. This stickiness implies that money in non-neutral and that the choice of monetary policy affects the dynamics of the economy and the welfare of individuals. Although having monetary non-neutrality is essential for any meaningful discussion about optimal monetary policy, including staggered wage setting in the model has the benefit of being able to incorporate the fact that high-skilled individuals reset their wages more frequently than low-skilled workers.

Calibrating the skill-specific probability of wage adjustment to the volatility of each real wage series and adopting an otherwise standard parametrization, I show that the model successfully predicts that high-skilled hours are more volatile than low-skilled hours. Additionally, the model successfully predicts that the correlation between GDP and low-skilled wages is lower than the correlation between GDP and high-skilled wages. I show that these predictions are robust to the types of shocks included in the model and the parameters in the monetary policy rule. However, if the probability of wage adjustment is forced to be the same for each skill type, the model no longer makes these successful predictions. Clearly, having these skill-specific parameters is one way to match the salient facts on skill-specific variables and has the advantages of being consistent with the evidence on wage adjustment and allows for monetary non-neutrality.

In the normative section of the paper I show that there are welfare losses from price and wage dispersion just as in Erceg et al. (2000), but there is an additional cost of wage dispersion in that in causes misallocation. Since relative wages appear in the firm's factor demand curves, as long as one group has sticky wages, both groups will suffer welfare losses. In other words, even if one group of workers has completely flexible wages, its welfare decreases as the other group's wages becomes stickier. The objective of monetary policy is to minimize these welfare losses.

In the spirit of Taylor (1993) and more recently Schmitt-Grohe and Uribe (2007), I solve for the optimal policy coefficients when monetary policy is a linear function of observable variables. Several conclusions are drawn from this exercise. First, in the baseline parametrization, high-skilled individuals prefer a stronger response to price inflation and a weaker response to wage inflation compared to low-skilled individuals. This is reasonable because low-skilled individuals experience more disutility from wage dispersion due to their relatively infrequent wage adjustment. That said, compared to ad hoc rules, the differences between the optimal rule from the perspective of the high-skilled worker to the low-skilled worker is relatively small in terms of consumption equivalents, where the consumption equivalent is defined as the percent of consumption the worker would have to be compensated in one regime to be indifferent between living in that regime versus an alternative one. Next, responding to deviations in output from its steady state level always decreases the welfare of both skill types. The idea here is that responding to these deviations actually increases the discrepancy between the flexible price equilibrium and the sticky price and wage equilibrium which reduces welfare. Finally, I show that the optimal simple rule comes very close to replicating the welfare results from solving a full blown Ramsey problem. This is interesting because the Ramsey interest rate rule is complicated in that it requires policy makers to solve a complicated optimization problem and respond to a long list of variables, some of which are not observable.

This paper shows that it is indeed possible to build a relatively simple model that captures some of the salient labor market facts of high and low-skilled workers over the business cycle and allows for a non-trivial role of monetary policy. From a normative perspective, however, it appears to make little quantitative difference whether or not the policy maker takes both groups into account or simply maximizes the utility of a stand-in representative agent. Although this paper explores heterogeneity along only one dimension, this indicates that adopting the representative agent assumption in a typical New Keynesian model may not change the optimal policy prescriptions by any degree of significance. This would be a relief to policy makers who believe the New Keynesian model is an effective way to model monetary policy since keeping track of aggregate statistics is less formidable than gathering and responding to the infinite types of heterogeneity in the labor market.

2 Literature Review

The fact that hours per person vary by demographic group is well documented. Clark and Summers (1981), Rios-Rull (1996), and Jaimovich and Siu (2009) show that younger individuals have much more volatile hours than older individuals. An additional source of volatility heterogeneity is education. Jaimovich and Siu, Gomme et al. (2005), and Lindquist

(2004) show that the volatility of hours is higher for lower educated groups. Moreover, Lindquist documents that the wages of the least skilled are less volatile than the most skilled.

The empirical literature on nominal wage rigidity is vast, especially downwards nominal rigidity. Recent studies, including Barattieri et al. (2014), Le Bihan et al. (2012), and Elsby (2009), use a mix of firm and individual level panel data to document the prevalence of wage stickiness. Barattieri et al. estimate that the probability of adjusting a nominal wage in any given quarter ranges from 21 to 27 percent, while Le Bihan et al. estimate a figure closer to 38 percent. Other authors such as Daly et al. (2012) use the Current Population Survey's (CPS) Monthly Outgoing Rotation Group (MORG) to track wage stickiness over time. The advantage to using the MORG is that it has been conducted since 1979, whereas the aforementioned studies that use panel data are of a much shorter duration. The disadvantage to the MORG is that subjects are asked about weekly earnings twice and the interviews are separated by a year.[2] Another strand of literature estimates the degree of wage stickiness in the context of medium scale Dynamic Stochastic General Equilibrium (DSGE) models. Both Christiano et al. (2005) and Smets and Wouters (2007) estimate a low average duration of wage contracts with the former estimate around three quarters and the latter around five.

In terms of modeling strategy, my paper is most similar to Erceg et al. (2000) who put nominal price and wage rigidities in a DSGE model and analyze optimal monetary policy. Several authors have studied New Keynesian models with ex ante heterogeneous agents to answer different questions. Eggertsson and Krugman (2012) analyze the relationship between monetary policy, borrowing constraints and debt deleveraging. Monacelli (2009) uses two types of agents to explain the response of consumer durable goods to monetary policy shocks, while Gali et al. (2007) use heterogeneous agents to explain the empirical impulse responses to changes in government spending. Most recently, Gornemann et al. (2012) build an incomplete markets model with heterogeneous agents, search and matching frictions, and nominal price rigidities to examine how monetary policy shocks affect income and wealth inequality. Until now, however, no paper has looked at an economy with price and wage rigidities where the source of heterogeneity stems from individuals reset wages with different frequencies and are imperfect substitutes in production.

Finally, my paper is related to the literature that quantitatively evaluates the welfare properties of different monetary policy rules in New Keynesian models. Lee (2010) considers optimal monetary policy in an economy with a continuum of heterogeneous agents with idiosyncratic labor income and imperfect risk sharing. Schmitt-Grohe and Uribe (2006)

[2] The Panel Survey of Income Dynamics (PSID) suffers from the same disadvantage since subjects are interviewed annually. See Card and Hyslop (1997) for an example of using this data set.

numerically solve for the Ramsey interest rate and tax policy in a medium scale representative agent New Keynesian model and in a 2007 paper the authors evaluate the welfare properties of simple interest rate rules. Faia and Monacelli (2007) derive the optimal simple interest rate rule in an economy with financial frictions, whereas Faia (2008) performs a similar exercise in an economy with price rigidity and search and matching frictions in the labor market. I follow the welfare exercises considered in all of these papers.

3 Empirical Motivation

I use data from the CPS-MORG from 1979-2012. Subjects in the CPS are interviewed for four consecutive months, then take eight months off, and then are interviewed for four more months. Members of the MORG are those in their fourth and eighth month of participation and are asked questions regarding their weekly earnings and hours worked. I focus on non-self employed individuals between the ages of 16-64. High-skilled individuals are those with more than a high school education and low-skilled workers are those with a high school degree or less. I group the monthly observations into quarters and weight each observation by its sample weight, in the case of hours worked, and the product of its sample weight and hours worked, in the case of wages. In this way, individuals who work more hours are weighted more heavily when calculating statistics.[3] Further details are provided in the appendix. Summary statistics over the entire sample period are displayed in Table 1.

3.1 Hours Worked

Average hours worked per person is calculated as the sum of weighted usual hours worked divided by the sum of the sample weights. This includes individuals both in and out of the labor force. The behavior of hours worked for both skill types leading up to and just following the Great Recession are displayed in Figure 1. Although hours worked substantially dropped in the aggregate, the decline in the less educated groups is much more stark. The labor input of low-skilled individuals was 15 percent lower in 2009Q3 than at the beginning of 2007, whereas the labor input for high-skilled individuals never dropped by more than ten percent. This corroborates Elsby et al.'s (2010) analysis of the Great Recession. They find that unemployment rose substantially more for low-skilled groups over the time period.

While Figure 1 shows that the response of hours by skill group differed significantly over the last several years, this is only one episode and the cyclical portion of the series was not isolated. With that in mind, I detrend each hours series over the entire time period using the HP filter and a smoothing parameter of 1600. Figure 2 shows that low-skilled hours are much more volatile than high-skilled labor, increasing much more in expansions

[3] I experiment with different weighting schemes for wages including weighting by the CPS variable earnwt. The magnitudes change slightly, but the qualitative patterns do not.

and dropping by much more in recessions. Over the entire time period, low-skilled hours are 68 percent more volatile than high-skilled hours. At the same time, low-skilled hours are slightly more procylical than skilled hours.

3.2 Wages

Individuals in the sample are either paid by the hour or they are salaried. If someone works on an hourly basis, she reports the hourly wage to the CPS. The wages for non-hourly workers equals usual weekly earnings divided by usual hours worked. Quarterly wages for each skill group are constructed by taking the weighted sum of individual wages and dividing by the sum of the weights. Figure 3 shows that high-skilled wages are more volatile than low-skilled wages, but low-skilled wages are slightly more countercyclical. The countercyclicality could be a consequence of changing labor force composition as emphasized in Barsky et al. (1993), Bils (1985), and Kydland and Prescott (1993). This could affect the volatility of wages too if most of the entry and exit from the labor force occurs on the tails of the distribution. However, as long as the composition bias does not disproportionately affect one group over the other, this should not be an issue.

To test for the extent of these composition biases, I compute the median of skilled and low-skilled wages for each period. The results are also contained in Table 1. As expected, the contemporaneous correlations between wages and real GDP fall in absolute value, although they are still slightly less than zero. More importantly, the median skilled wage is still slightly more volatile than the median low-skilled wage. This finding is robust to different weighting techniques, which indicates that the excess volatility of high-skilled wages relative to low-skilled wages is not completely attributed to entry and exit over the business cycle.

3.3 Wage Stickiness

I document the degree to which wag stickiness varies with education using the San Francisco Federal Reserve's "Wage Rigidity Measure", the results of which are displayed in Figure 4. The vertical axis is the proportion of workers who report no nominal wage change after one year. The index breaks down this calculation into four education categories: less than high school, high school graduate, some college, and college graduate. I weight each group by its relative population at each moment in time to construct an index that corresponds to my high-skill and low-skill groups. On average, low-skilled individuals are less likely to receive nominal wage changes over the course of the year. Using the same data, Daly et al. (2012) conclude that wage rigidity is similar across industries, so the result that less skilled individuals have more wage stickiness than high skilled individuals is not a consequence of skill types concentrating in particular industries.

4 Model

The model consists of two types of households, high-skilled and low-skilled, with a continuum of individuals of each type. In total, there is a mass of s high-skilled individuals and $1-s$ low-skilled individuals. Individuals sell their labor to an agency, which packages the labor and sells it to firms. With some probability, individuals cannot adjust the wage at which they offer their labor services to the agency and are stuck with the previous period's wage. There is perfect insurance within a skill type and utility is separable in consumption and leisure, which implies that consumption is equal across household members, but leisure is not. There is not perfect risk sharing between households. Instead, there is a risk free bond in which both households can invest.

There is a continuum of intermediate good firms who hire labor, produce a differentiated good, and sell it to a perfectly competitive final goods firm. Similar to the wage setting mechanism, intermediate good firms adjust prices with some constant probability.

Monetary policy is set by the central bank. In this section and the next, I specify a simple monetary policy rule and consider the model dynamics under it. In Section 6 I consider optimal monetary policy rules.

4.1 Employment Agency

I follow Erceg et al. (2000) and Gali (2011) in specifying an employment agency which buys the heterogeneous labor offered by individuals within a household, packages it, and sells it to firms. There is an agency for each type of household, which is indexed by $j \in \{s, u\}$. The agency purchases $n_{j,t}(i)$ units of labor from individual i in skill group j at a wage of $W_{j,t}(i)$. The packaging of the heterogeneous labor input takes place according to a constant elasticity of substitution (CES) production function with $\nu_{j,t}$ being the (potentially time varying) elasticity of substitution. The firms sell the aggregate labor input, $n_{j,t}$, to firms at price, $W_{j,t}$. Their problem is to choose $n_j(i)$ to maximize

$$W_{j,t}\left(\int_0^1 n_{j,t}(i)^{\frac{\nu_{j,t}-1}{\nu_{j,t}}}di\right)^{\frac{\nu_{j,t}}{\nu_{j,t}-1}} - \int_0^1 W_{j,t}(i)n_{j,t}(i)di.$$

Now and throughout the remainder of the paper, upper case letters denote nominal variables and lower case letters denote real variables. The maximization problem gives rise to a system of demand equations

$$n_{j,t}(i) = n_{j,t}\left(\frac{W_{j,t}(i)}{W_{j,t}}\right)^{-\nu_{j_t}}. \tag{1}$$

Since $\upsilon_{j,t} > 1$, labor demand for type i is decreasing in its own wage. The aggregate wage index, $W_{j,t}$, is derived using the condition that the employment agency is perfectly competitive and, therefore, earns no profits.

$$W_{j,t}^{1-\nu_{j,t}} = \int_0^1 W_{j,t}(i)^{1-\nu_{j,t}} di \tag{2}$$

4.2 Households

Household j has a continuum of members indexed by $i \in [0,1]$. There is perfect insurance within the household and utility is separable which implies that the consumption of each member will be the same. In each period, individual i chooses consumption and bond holdings to maximize

$$E_t \sum_{k=0}^{\infty} \beta^{t+k} \left[U(c_{j,t+k}(i)) - v(n_{j,t+k}(i)) \right]$$

subject to its budget constraint

$$c_{j,t+k}(i) + \frac{B_{j,t+k}(i) - B_{j,t+k-1}(i)}{P_{t+k}} + \frac{\zeta}{2}\left(\frac{B_{j,t+k}(i)}{P_{t+k}}\right)^2 \leq i_{t-1}\frac{B_{j,t+k-1}(i)}{P_{t+k}} + \frac{W_{j,t+k}(i)}{P_{t+k}} n_{j,t+k}(i) + \frac{\Gamma_{t+k}}{P_{t+k}}$$

and its labor demand curve (2). The budget constraint says that consumption plus asset accumulation is not greater than the sum of interest income, wage income and profits, Γ_{t+k} from owning the firm. The quadratic cost, $\frac{\zeta}{2}\left(\frac{B_{j,t+k}(i)}{P_{t+k}}\right)^2$ is introduced to ensure the existence of a steady state for bond holdings across households. ζ is chosen to be very small so that neither the steady state nor the dynamics of the model are changed.[4] The Euler equation is,

$$U'(c_{j,t+k})\left[1 + \zeta b_{t+k}\right] = \beta E_{t+k}\left[U'(c_{j,t+k+1})\frac{1+i_t}{1+\pi_{t+1}}\right] \tag{3}$$

where π_t is inflation in period t. Note that the Euler equation is the same across all individuals so the i index can be suppressed. The Fisher equation relating the real interest rate to the nominal interest rate is $1 + r_t = E_t\left[\frac{1+i_t}{1+\pi_{t+1}}\right]$.

In any period, a fraction, $1 - \xi_j$, of workers can adjust their nominal wages. Every other worker has to keep the previous period's wage and supply enough labor to meet demand, i.e. equation (1). The optimality condition of a worker able to update his wage in period t is

$$W_{j,t}^{\#} = \frac{\nu_{j,t}}{\nu_{j,t} - 1}\left[\frac{E_t \sum_{k=0}^{\infty} (\beta\xi_j)^k n_{j,t+k|t} U'(c_{j,t+k}) mrs_{j,t+k|t}}{E_t \sum_{k=0}^{\infty} (\beta\xi_j)^k n_{j,t+k} U'(c_{j,t+k})/P_{t+k}}\right] \tag{4}$$

where $mrs_{j,t+k|t} = \frac{v'(n_{j,t+k|t})}{U'(c_{j,t+k})}$ is the marginal rate of substitution for a worker in skill class j.

[4] In the quantitative exercise, ζ is less than one tenth of a percent of steady state consumption.

The marginal utilities at any time $t+k$ are independent of when the worker last updated his wage since there are complete financial markets within households. If wages were completely flexible so that $\xi_j = 0$, the above condition would reduce to

$$\frac{W_{j,t}^{\#}}{P_t} = \frac{W_{j,t}}{P_t} = \frac{\nu_{j,t}}{\nu_{j,t}-1} mrs_t.$$

This implies that real wages would be a time varying markup over the marginal rate of substitution. Since households cannot update wages in every period, however, they must account for expected economic conditions when posting their wages today. Finally, using the fact that all individuals who update their wages choose the same wage, equation (2) can be rewritten as

$$W_{j,t}^{1-\nu_{j,t}} = (1-\xi_j) W_{j,t}^{\#(1-\nu_{j,t})} + \xi_j W_{j,t-1}^{1-\nu_{j,t}}. \tag{5}$$

In other words, wages today are a weighted combination of the optimal reset wage and last period's wage.

4.3 Final Goods Firm

The final goods firm serves a purpose analogous to the employment agency from Section 4.1. The final goods firm is perfectly competitive. It purchases heterogeneous intermediate goods, assembles them, and sells the final product to consumers. The assembly takes place according to a constant elasticity of substitution production function, $y_t = \left(\int_0^1 y_t(i)^{\frac{\epsilon_t - 1}{\epsilon_t}} di \right)^{\frac{\epsilon_t}{\epsilon_t - 1}}$, where the elasticity of substitution, ϵ_t, is time varying. Their problem is to choose $y_t(i)$ to maximize

$$P_t \left(\int_0^1 y_t(i)^{\frac{\epsilon_t - 1}{\epsilon_t}} di \right)^{\frac{\epsilon_t}{\epsilon_t - 1}} - \int_0^1 P_t(i) y_t(i) di.$$

This gives rise to the system of demand equations,

$$y_t(i) = y_t \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_t}. \tag{6}$$

Under the assumption of perfect competition, the final goods firm makes zero profits. Using the zero profit condition the aggregate price index, P_t, can be solved for.

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon_t} di \right)^{\frac{1}{1-\epsilon_t}} \tag{7}$$

Hence, the aggregate price index is simply a weighted average of the intermediate good prices.

4.4 Intermediate Goods Firms

Intermediate goods firms purchase high-skilled and low-skilled labor to produce a heterogeneous good and sell it to the final goods firm. Since each firm faces a downwards sloping demand curve for its product it gets to set its price. However, in each period, a fraction, ϕ, of firms cannot reset their price having instead to keep last period's price. The production function for intermediate good firm i is

$$y_t(i) = A_t \left[(h_t N_{s,t}(i))^{\frac{\sigma-1}{\sigma}} + ((1-h_t)N_{u,t}(i))^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}.$$

A_t is total factor productivity, while h_t is a share term which fluctuates over time to account for relative skill shocks. σ is the elasticity of substitution between the two types of labor. If $\sigma = 0$, the inputs are perfect complements and as $\sigma \to \infty$, the inputs become perfect substitutes. In the special case $\sigma = 1$, the production function is Cobb Douglas. In the appendix I show that the symmetric real marginal cost for each firm is

$$mc_t = \frac{\left[h_t^{\sigma-1} w_{s,t}^{1-\sigma} + (1-h_t)^{\sigma-1} w_{u,t}^{1-\sigma} \right]^{\frac{1}{1-\sigma}}}{A_t}. \tag{8}$$

In other words, marginal cost is proportional to the ratio of a weighted average of wages and TFP. As a consequence of constant returns to scale, marginal cost is not a function of output. Also, define the nominal wage index as

$$W_t = P_t mc_t A_t. \tag{9}$$

The price decision is dynamic. A firm that can update in period t takes expectations of future economic conditions into consideration, since there is a possibility it will not be able to update. The problem is to choose a reset price, $P_t^{\#}(i)$ to maximize

$$E_t \sum_{k=0}^{\infty} \Lambda_{t+k} \phi^k \left[\frac{P_t^{\#}(i)}{P_{t+k}} y_{t+k}(i) - mc_{t+k} y_{t+k}(i) \right]$$

subject to equation (6). Λ_{t+k} is the stochastic discount factor. The optimality condition is

$$P_t^{\#}(i) = P_t^{\#} = \frac{\epsilon_t}{\epsilon_t - 1} \frac{E_t \sum_{k=0}^{\infty} \Lambda_{t+k} \phi^k mc_{t+k} y_{t+k} P_{t+k}^{\epsilon}}{E_t \sum_{k=0}^{\infty} \Lambda_{t+k} \phi^k y_{t+k} P_{t+k}^{\epsilon-1}}. \tag{10}$$

In the case of complete flexibility, the optimality condition reduces to

$$\frac{P_t^{\#}}{P_t} = \frac{\epsilon_t}{\epsilon_t - 1} mc_t$$

which says price is a time varying markup of marginal cost. Using the price rule, the price index can be rewritten as

$$P_t^{1-\epsilon_t} = (1-\phi) P_t^{\#^{1-\epsilon_t}} + \phi P_{t-1}^{1-\epsilon_t}. \tag{11}$$

So today's prices are a weighted combination of the reset price and yesterday's prices.

4.5 Monetary Policy

In the descriptive analysis that follows, monetary policy follows the Taylor-type rule:

$$\log(1+i_t) = (1-\rho_i)\left(\phi_w \log(1+\pi_{w,t}) + \phi_p \log(1+\pi_{p,t}) + \phi_y \log\left(\tfrac{y_t}{y_{ss}}\right)\right) + \rho_i \log(1+i_{t-1}). \tag{12}$$

$\pi_{w,t}$ is wage inflation and $\pi_{p,t}$ is price inflation.[5] This rule says that the central bank adjusts interest rates in response to changes in both wage and price inflation and output growth. When I consider Ramsey optimal policy in Section 6, the interest rate rule can respond to additional variables.

4.5 Shocks

The TFP and relative productivity shock processes are

$$\log(A_t) = \rho_a \log(A_{t-1}) + \varepsilon_{a,t} \tag{13}$$

$$\log(h_t) = (1-\rho_h)\log(h_{ss}) + \rho_h \log(h_{t-1}) + \varepsilon_{h,t} \tag{14}$$

where ε_i is normally distributed with mean 0 and standard deviation σ_i.

Define the markups for high-skilled wages, low-skilled wages, and prices as

$$\varphi_{s,t} = \frac{\nu_{s,t}}{\nu_{s,t} - 1}$$

$$\varphi_{u,t} = \frac{\nu_{u,t}}{\nu_{u,t} - 1}$$

$$\varphi_{p,t} = \frac{\epsilon_t}{\epsilon_t - 1}.$$

[5] Wage inflation is defined as $\frac{W_t}{W_{t-1}} - 1$.

The markup shock processes are

$$\log(\varphi_{j,t}) = (1-\rho_j)\log(\varphi_{j,ss}) + \rho_j \log(\varphi_{j,t-1}) + \varepsilon_{j,t} \tag{15}$$

where ε_j is normally distributed with mean 0 and standard deviation σ_j.

4.6 Aggregation and Market Clearing

The appendix contains a detailed analysis of aggregation. I summarize the results here. Aggregate output is

$$y_t = \frac{A_t \left[h_t N_{s,t}^{\frac{\sigma-1}{\sigma}} + (1-h_t) N_{u,t}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}}{v_t} \tag{16}$$

where $v_t = \int_0^1 \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_t} di$ is the deadweight loss due to price dispersion. The other equilibrium conditions include:

$$N_{s,t} = s n_{s,t} \tag{17}$$

$$N_{u,t} = (1-s) n_{u,t} \tag{18}$$

$$c_t = s c_{s,t} + (1-s) c_{u,t} \tag{19}$$

$$B_{s,t} + B_{u,t} = 0 \tag{20}$$

$$y_t = c_t + \frac{\varsigma}{2} \left(b_{s,t}^2 + b_{u,t}^2 \right). \tag{21}$$

Equations (17) and (18) are the market clearing conditions for each type of labor. Equation (19) says that total consumption is the sum of share weighted consumption and equation (20) is the bond market clearing condition. Finally, equation (21) says output equals consumption plus bond holding costs.

5 Quantitative Properties of the Model

In this section I consider the properties of the model. First, I discuss how the parameters are chosen. Some of them are calibrated and the remainder are taken from other papers. Next, I simulate the model and compare the volatility of hours and wages in the model to those in the data. Finally, I show the response of endogenous variables to TFP, relative productivity, and markup shocks under different monetary policy rules and different levels of wage stickiness.

5.1 Parametrization

The elasticity of substitution parameters within a worker class and between intermediate good firms are set to ten, implying a ten percent steady state markup of wages and prices. σ is set to 1 implying the production function is Cobb Douglas. The value of the probability of price readjustment, ϕ, is 0.67 which is a compromise between the micro estimates of Bils and Klenow (2004) on the frequency of price adjustments and the DSGE estimates of Christiano et al. (2005) and Smets and Wouters (2007). This implies that prices are changed every three quarters on average. I take $\gamma = 1$ and $\chi = 1$ implying preferences are log over consumption and a Frisch elasticity of one.

The subset of parameters that are calibrated include: β, h_{ss}, θ_s, θ_u, and s. I use the same data source that I discussed in Section 2. I match an annual risk free real interest rate of two percent, steady state usual hours per week by each type of worker, an average skill premium of 1.53, i.e. $\frac{w_s}{w_u} = 1.53$, and the average share of highly educated workers in the data.

I set the autoregressive parameters for each stochastic process equal to 0.97. The standard deviations of the relative productivity shock and the price and wage markup shocks are set to 0.005.

I choose the standard deviation of the TFP shock, and the Calvo wage parameters, ξ_s and ξ_u, to match the volatility of real GDP and the volatilities of real hourly wages for each skill type. This implies $\sigma_a = 0.0071$, $\xi_s = 0.34$ and $\xi_u = 0.72$. The full set of parameters is displayed in Table 2.

5.2 Quantitative Evaluation

Table 3 compares the second moments of the simulated data from the model to the actual data. Both the actual and simulated data are logged and HP filtered with a smoothing parameter of 1600. Considering that many potential first-order features of the real world are excluded from the model, such as capital accumulation, adjustment costs, and habit formation, the model performs well in matching the moments from the data. It successfully predicts that high-skilled hours are less volatile than low-skilled hours, that high-skilled hours are less correlated with output than low-skilled hours, and that high-skilled wages are more correlated with output than low-skilled wages.

To what extent are these results attributable to the main mechanism posed here, namely that each skill type has a specific Calvo parameter? The fourth column shows the results when I set $\xi_s = \xi_u = \bar{\xi}$, where $\bar{\xi}$ is the employment weighted average wage stickiness. In this case, the skill types have approximately the same volatility of their wages and hours. Moreover, this parametrization implies that high-skilled hours are more procyclical than low-skilled hours which is not true in the data. Hence, the addition of different Calvo parameters improves the model's fit along these dimensions.

To determine the extent to which the results are driven by the combination of shocks in the model, I simulate the model when there are only TFP shocks. The fifth column shows the results when the model is simulated with just TFP shocks. While the decline in the absolute volatilities of labor market variables is a consequence of having fewer shocks in the model, the relative volatilities are similar to those in the model with all the shocks. Moreover, the correlations of labor market variables to output remain qualitatively similar to the correlations in the data.

Exploring the generality of these results, I consider three alternative parameter value specifications in the nominal interest rate rule. The sixth column keeps $\phi_\pi = 1.5$ and $\phi_w = 0$ but changes the coefficient on deviations in output from steady state output to $\phi_y = 0.125$. [6] The seventh column sets $\phi_\pi = 1$, $\phi_w = 0.5$, and $\phi_y = 0$, so the policymaker targets both price and wage inflation. The eighth column has the same weights on price and wage inflation, but sets $\phi_y = 0.125$. Each of these specifications predicts the same qualitative features that are present in the original specification. Additionally, in each specification high-skilled wages are more volatile than low-skilled wages, even though the wage stickiness parameters are fixed to their values in the baseline experiment. The robustness of the predictions across specifications provides some confidence as the discussion turns to optimal policy. First, however, it is instructive to look at the impulse responses to a technology shock under various interest rate rules.

5.3 Impulse Responses

Figures 5-9 show the impulse response functions of selected endogenous variables to a one standard deviation increase of each stochastic shock. Except for the nominal interest rate, each response is divided by its steady state so the interpretation is in terms of percent changes from steady state. I simulate the model under four different specifications. The first three differ in terms of the parameters in the nominal interest rate rule. The "price targeting rule" assigns $\phi_\pi = 2$ and 0 to the other parameters and the "wage targeting rule" assigns $\phi_w = 2$ and 0 to the other parameters. The "balanced rule" sets $\phi_\pi = \phi_w = 0.75$ and the other parameters to 0. The fourth specification sets all the Calvo parameters equal to 0 which implies wages and prices are completely flexible. With price and wage flexibility, the nominal interest rate does not affect real variables and the only requirement is that it satisfies the Taylor principle for determinacy.

The flexible level of output rises in response to a positive TFP shock, as seen in Figure 5. Moreover, since utility is log over consumption, income and substitution effects cancel, producing a change in neither high-skilled nor low-skilled hours. This means that the percent increase in output is equal to the percent increase in TFP. The percent increase in real wages of both types also equals the percent increase in TFP. When wages and prices are sticky, the price markup and the wage markups move endogenously. A policy rule that strictly targets price inflation minimizes movement in the price markup, but not the wage markup, whereas

[6] Note that if output growth was expressed in annual rather than quarterly terms, I would have $\phi_y = 0.5$ as in the traditional Taylor rule.

the situation is reversed when the policy rule targets wage inflation. After a TFP shock the price markup rises since some firms who would like to reduce their prices cannot, while the wage markup falls as workers who would like to increase their wages cannot. Targeting price inflation reduces the increase in the price markup, but allows the wage markup to fall. Taken together, the price targeting rule is relatively expansionary since output rises above its flexible level. Note that the percent increase in low-skilled hours is approximately 50 percent higher than the response of high-skilled hours, reflecting the fact that low-skilled individuals have stickier wages. Low-skilled hours are also more persistent than high-skilled hours since the former workers are slower to update their wages. This is further demonstrated in the bottom panels where the percent increase in high-skilled real wages exceeds the percent increase in low-skilled wages.

While the wage responses are similar to their counterparts under a price targeting rule, the wage targeting rule causes hours of both types to drop, implying a more muted response in output relative to its flexible price and flexible wage level. The reduction in hours is a consequence of the price markup rising, thus reducing demand for labor, and the wage markups failing to fall. The balanced rule, as suggested by its name, produces responses in between the two strict targeting rules. The price (wage) markup rises (falls) by more (less) than it would under the price targeting rule, but less (more) than it would under the wage targeting rule.

When the relative productivity of high-skilled workers rises, as it does in Figure 6, the flexible price and wage responses are fairly intuitive. The labor demand curve expands for high-skilled workers, but contracts for low-skilled workers. Since consumption rises for high-skilled workers, but falls for low-skilled workers (not shown here), shifts in labor supply mitigate the extent to which hours change, but increase the change in wages. Since output is relatively intensive in high-skilled labor, the relative productivity shock is somewhat expansionary. If prices and wages are sticky, however, the responses change dramatically. The increase in relative productivity exacerbates the change in hours as high-skilled workers cannot raise their wages fast enough to take advantage of the increase in their productivity and low-skilled workers cannot reduce their wages fast enough in response to the decrease in their productivity. The net result is that high-skilled workers are relatively cheap compared to low-skilled workers which causes bigger changes in hours compared to the case of flexible prices and wages. These responses are fairly robust to the choice of nominal interest rate policy rule.

Figure 7 shows the response to a one standard deviation increase in the price markup. In the case of flexible prices and wages, this acts as a tax on the two types of labor. Hours and wages of each type decline. When prices and wages are sticky, some intermediate good producers cannot raise their prices on impact which reduces the contractionary effect of the markup shock. On the other hand, real wages do not fall as fast as they do under the flexible case which increases the wage markup and depresses output. Which effect dominates is contingent on the nominal interest rate rule. If the rule targets price inflation, the increase in the nominal interest rate is sufficiently big to decrease the price level and raise the real price of intermediate good firms. This reduces the expansionary effect of sticky prices and causes output to fall relative to its flexible level. Since low-skilled wages are stickier than high-skilled wages, their hours fall more in percentage terms than high-skilled hours. If the rule targets wage inflation, the increase in wage markups are reduced and the offsetting decrease in price markups are restored. This causes output to be more expansionary relative to its flexible price and wage level.

Figures 8 and 9 show the effects of an exogenous high-skilled wage and low-skilled wage markup respectively. When wages are sticky, the exogenous increase in wage markups is mitigated since some workers cannot adjust their wages. The big difference between Figures 8 and 9 is the magnitude of the response to labor market variables. An increase in the high-skilled wage markup increases wages of the high-skilled by an order of magnitude more than the increase in low-skilled wages caused by an increase in the low-skilled wage markup. The decrease in hours of both types is also much smaller after a low-skilled markup shock. Hence, analogous to the case where price stickiness mitigates the contractionary effects of a price markup shock, wage stickiness offsets the contractionary effects of a wage markup shock and the offsetting effect is the strongest when the stickier of the two wage groups receives the shock.

6 Optimal Monetary Policy

I consider two types of monetary policy. The first is an unconstrained Ramsey plan in the sense that the nominal interest rate can respond to any economic variable, assumes that the policy maker understands the structure of the underlying economy, and can commit to a policy. The second is a constrained Ramsey plan, wherein the nominal interest rate rule is restricted to be a linear function of a small number of observable variables. In the context of related literature, the unconstrained Ramsey plan proceeds along the lines of Schmitt-Grohe and Uribe (2006) and the constrained Ramsey plan follows Schmitt-Grohe and Uribe (2007).

6.1 Policy Tradeoffs

There are three distortions in the model economy (wage and price stickiness and incomplete financial markets) and one instrument (the nominal interest rate). In general, optimally choosing the nominal interest rate will not be enough to restore the flexible price equilibrium. To better understand the policy tradeoffs, I show how both price and wage dispersion affect welfare. Welfare for a person i in skill group j at time t is defined recursively by

$$V_{j,t}(i) = \log(c_{j,t}(i)) - \tfrac{\theta_j}{1+\chi} n_{j,t}(i)^{1+\chi} + \beta E_t V_{j,t+1}(i).$$

In writing the value function with a subscript, t, it is implicit that it is conditional on the realization of a particular state. Integrating over every member of the skill group, $V_{s,t} = \int_0^1 V_{s,t}(i)di$ and $V_{u,t} = \int_0^1 V_{u,t}(i)di$, gives the aggregate welfare for skill group j. Recognizing that complete insurance within skill types requires $c_{j,t}(i) = c_{j,t}$, aggregate welfare for the high skilled group is

$$V_{s,t} = s\log(c_{s,t}) - \tfrac{\theta_s}{1+\chi} \int_0^1 n_{s,t}(i)^{1+\chi} di + \beta E_t V_{s,t+1}$$

and likewise for the low-skilled group. Substituting in the demand for type i labor implies

$$V_{s,t} = s\log(c_{s,t}) - \tfrac{\theta_s}{1+\chi} v_{s,t}^w n_{s,t}^{1+\chi} + \beta E_t V_{s,t+1} \tag{22}$$

where $v_{s,t}^w = \int_0^1 \left(\frac{w_{s,t}(i)}{w_{s,t}}\right)^{-\nu_s(1+\chi)} di$ and likewise for low skilled workers. If wages were perfectly flexible, there would be no wage dispersion and $v_{s,t}^w = v_s^w = s$, $\forall t$. All else equal, an increase in average wage dispersion reduces welfare because it impedes the disutility of labor effort.

Since bonds are traded between households, one cannot substitute output for consumption in (27). However, if financial markets are complete between, as well as within, skill types, $c_{j,t} = \mu_j y_t$ where μ_j is some constant fraction. If this is true, one can show

$$V_{u,t} = (1-s)(\log(A_t) - \log(v_t^p)) - v_{u,t}^w \tfrac{\theta_u}{1+\chi} n_{u,t}^{1+\chi} + \beta E_t V_{u,t+1} + K_{1,u} \tag{23}$$

$$V_{s,t} = s(\log(A_t) - \log(v_t^p)) - \tfrac{\theta_s}{1+\chi} v_{s,t}^w n_{s,t}^{1+\chi} + \beta E_t V_{s,t+1} + K_{1,s} \tag{24}$$

where K_j is a time invariant constant. Price and wage dispersion enter directly in terms of v_t^p and $v_{j,t}^w$ and clearly reduce welfare.

If both prices and wages are sticky, there will be price and wage dispersion unless the policy maker follows a strict price inflation or wage inflation targeting rule. If the former is followed, the nominal interest rate adjusts so that firms never have to update their prices, which eliminates price dispersion. If the latter is followed, the nominal interest rate rule is adjusted so that changes in the nominal wage index are 0, but skill specific inflation could be positive or negative. Alternatively, one could adjust the interest rate so that $\pi_{s,t} = 0$ or $\pi_{u,t} = 0$, but not both. However, as a quantitative matter, specifying $\pi_t^w = 0$, makes inflation of each type close to 0.

Regardless, strict wage inflation targeting will not eliminate price dispersion and, in fact, will tend to exacerbate it. Similarly, strict price inflation targeting exacerbates wage dispersion. The logic works as follows. Real wages adjust in response to productivity and markup shocks. They can adjust through changes in nominal wages or nominal prices. Eliminating price dispersion makes all the adjustment happen through nominal wages, but that increases wage dispersion, since only a fraction of workers can adjust their wages. Meanwhile, eliminating nominal wage dispersion requires that marginal cost change over time, which leads to price dispersion.

To obtain a qualitative feel for these tradeoffs, Figure 10 shows how price and wage dispersion change with the policy coefficients on wage and price inflation in the nominal interest rate rule. The figures in the top row show as the coefficient on wage inflation, ϕ_w, increases, average wage dispersion decreases for both skill types, but more so for low skilled since they are subject to stickier wages. Because nominal wage inflation is the product of real wage inflation and price inflation, increasing ϕ_w initially decreases average price dispersion, but eventually increases it. The second row shows that a stronger price inflation response reduces average price dispersion and increases average wage dispersion over almost the entire range. In summary, adding two skill groups to the New Keynesian model preserves the basic tradeoff between responding to price and wage inflation.

While the basic tradeoff is preserved, the skill groups have some complementarity effects on each other that are absent in the standard model. Examining equations (23) and (24) shows that wage and price dispersion are detrimental to welfare, but there is an additional cross-group effect that is not captured in these terms. The firm's labor demand for one skill group is a function of both of their wages, which means that nominal wage rigidity distorts the factor demand for each type of labor. To properly identify the welfare loss of misallocation between skill groups from misallocation within skill groups due to wage dispersion, I consider a case where the two groups are exactly the same in terms of their population shares, parameters in their utility functions, and share in production, but have different Calvo parameters. In particular, I set $\xi_s = 0$ and $\xi_u = 0.90$ implying that there is no nominal rigidity, and therefore no wage dispersion, for high-skilled workers, but low skilled workers on average reset their wages once every ten quarters. I vary $\phi_w \in [1, 3]$ and fix $\rho = \phi_y = 0$ and $\phi_\pi = 0.75$. The unconditional expected welfare of each group as a function of ϕ_w is plotted in Figure 11.

For low values of ϕ_w the low-skilled group is noticeably worse off than the high-skilled group. Since both groups are subject to between group misallocation and the same amount of price dispersion, the difference is entirely attributed to wage dispersion, or within group misallocation. As the central bank more aggressively responds to wage inflation, both groups experience welfare gains, but they are greater for the low-skilled. With a sufficiently strong response to wage inflation, both within and between group misallocation is eradicated and the expected welfare of the two groups converge. The fact that welfare is increasing in ϕ_w suggests that both groups will prefer a strong wage inflation response. However, this is holding all other parameters in the interest rate rule fixed. Optimal policy is considered next.

6.1 Ramsey Policy

The purpose of this section is to derive the Ramsey interest rate policy. The utilitarian social planner maximizes a weighted sum of the two groups' utilities,

$$V_t = s \int_0^1 V_{s,t}(i)di + (1-s) \int_0^1 V_{u,t}(i)di.$$

Figures 12-14 compare the impulse responses to each shock under the Ramsey interest rate rule to the strict price and wage inflation targeting rules. For each shock, I plot the impulse responses to the theoretical output gap, i.e. the difference between actual output and the flexible price and wage level of output, price inflation, and wage inflation. With the exception of a relative productivity shock, the Ramsey responses are always between the responses generated under the price and wage rules.

To obtain a quantitative sense of each rule, Table 4 compares selected second moments. The standard deviation of the nominal interest rate is smallest under the wage targeting rule and largest under the price targeting rule. Price inflation is less volatile under the price targeting rule, whereas wage inflation is less volatile under the wage targeting rule. The Ramsey rule strikes a balance in both cases. The nominal interest rate in the Ramsey rule is positively correlated with price inflation and negatively correlated with output and wage inflation. Since the nominal interest rate in the Taylor rules is a function of either price or wage inflation, the interest rate is perfectly correlated with the targeted variable, but otherwise the signs are the same as in the Ramsey rule.

6.2 Welfare Properties of Stylized Rules

In this section, I discuss the welfare properties of some simple interest rate rules. I begin by simulating the model under complete price and wage flexibility. Next, I compute the compensating variation for both skill types under a given regime. Let $V_j^f(\Omega_t)$ denote the value function of type j under flexible prices in a given state of the world at time t, Ω_t. I calculate the value of λ_j such that

$$E\sum_{t=0}^{\infty} \beta^t \left[U(c_{j,t}(1+\lambda_j^u)) - v(n_{j,t})\right] = EV_j^f(\Omega_t).$$

λ_j, which I henceforth call the consumption equivalent, is the fraction of household j's consumption process it would need to be compensated by to be indifferent between living in the flexible price and wage environment and a sticky price and wage environment under a particular monetary policy regime. If $\lambda_j > 0$ then the household prefers the flexible price environment to the sticky price environment. Under the functional forms assumed in the paper, I can analytically solve for the consumption equivalents.

$$\lambda_j^u = \exp((1-\beta)(EV_j^f(\Omega_t) - EV_j(\Omega_t))) - 1 \tag{25}$$

Tables 5 and 6 display eight different stylized interest rate rules. The consumption equivalents are multiplied by 100, so the interpretation is the percent of consumption the individual would need to be compensated by in the sticky price and wage economy to be indifferent between living in the two economies. The most conspicuous observation is that responding to output deviations from steady state in unambiguously harmful to both groups and the losses are quantitatively significant. This is consistent with Schmitt-Grohe and Uribe's (2007) findings in a representative agent economy. The intuition is that output rises when there is a positive productivity shock, but not by as much as in the flexible price case. Increasing the nominal interest rate in a "lean against the wind" policy reduces output, which takes the economy further away from its flexible price equilibrium.

Studying the simple interest rate rules leads to a few other notable observations. First, the welfare results look similar across both skill groups. A rule that one group finds more preferable is also preferred by the other one. Second, the welfare losses of responding to deviations in output from its steady state level are smaller when the interest rate is more persistent. Third, responding only to wage inflation produces smaller welfare losses than responding only to price inflation. Evidently, the costs of wage dispersion plus the added costs of between group misallocation outweigh the costs of price dispersion. However, responding strongly to either price or wage inflation results in rather small welfare losses for each group. In summary, while it appears that the optimal policy coefficients will be contingent on the welfare weights placed on the skill groups, the quantitative significance in terms of consumption equivalents is likely to be small.

6.3 Globally Optimal Simple and Implementable Rules

In this section, I consider the same linear nominal interest rate rule as in the last section, but search over a grid of parameters to find the optimal set, $\Phi = \{\rho_i, \phi_\pi, \phi_y, \phi_w\}$.[7] The

[7] I take $\rho_i \in \{0, 0.3, 0.6, 0.9\}$, $\phi_\pi \in [0,3]$, $\phi_w \in [0, 2.95]$, $\phi_y \in [0, 0.3]$. The width of a between point is 0.025.

coefficients are selected to maximize the social welfare function

$$V = \psi V_{s,t} + (1 - \psi) V_{u,t}$$

where ψ is the welfare weight the planner attaches to the high skilled group. I do this over a set of values of ψ. This experiment shows how the optimal interest rate rule changes with the planner's proclivity for one group over the other one. Table 7 contains the results.

Relative to the high-skilled group, the low-skilled group prefers a stronger response to wage inflation, a weaker response to price inflation, and less persistence in the interest rate rule. While it's difficult to gain intuition about the choice of the smoothing parameter, the preferred wage and price inflation coefficients complement the observations from the previous section. Low-skilled workers have stickier wages which, all else equal, causes them to prefer a stronger response to wage inflation. High-skilled workers have more flexible wages and, therefore, prefer a more balanced policy.

While the seventh through tenth columns show that the welfare effects of different optimal rules are quantitatively small, the low-skilled group's welfare actually exceeds its welfare relative to the flexible price equilibrium, provided the planner attaches a sufficiently large welfare weight to them. However, the maximum welfare gain of going from one set of welfare weights to another one is less that 0.05% of consumption. This is very small compared to the welfare changes from different ad hoc rules in Tables 5 and 6.

6.4 Digging into Welfare Losses

Solving for the optimal interest rate rules conditional on a welfare weight is informative, but it's more or less a black box. There are five shocks in the model and workers are different along other dimensions in addition to wage stickiness. In this section, I dig deeper into which aspects of the model cause workers to prefer one interest rate over another one. I set $\rho_i = 0$ and $\phi_y = 0$ and focus entirely on the responses to wage and price inflation. Also, the welfare weight is dichotomous, $\psi \in \{0, 1\}$.

I consider two types of experiments. In one, the parameters of the model are held to their values in Table 2. In the other, all the group specific parameters are set equal to each other, except for the Calvo parameters. Within each type, I measure how one shock in isolation affects the choice of policy parameters. I also consider the effect of equating the Calvo parameters across groups and simulating the model with all shocks. I use the unconditional consumption equivalents as a welfare metric.

The second through sixth columns contain the results from the baseline parametrization and the seventh through tenth contain the results from the alternative parametrization. When the model is simulated under the baseline parametrization and with all the shocks, the high-skilled workers actually prefer a stronger response to wage inflation than the low-skilled workers. On the other hand, when all the skill specific parameters are equalized, the group with stickier wages prefers a higher wage inflation coefficient. Hence, although the partial effect of stickier wages is to prefer a stronger wage inflation response, it is dominated by other skill specific parameters in the model. Additional evidence for this conclusion is provided in the next two rows where setting the wage Calvo parameters equal to each other causes the high-skilled workers to prefer a much higher response to wage inflation.

When the model under the baseline parametrization is simulated with just markup shocks (wage or price), high-skilled workers prefer a weak response to wage inflation and a strong response to price inflation and low-skilled workers prefer exactly the opposite. On the other hand, the skill groups agree on the wage inflation parameter when the model is simulated with just TFP or relative productivity shocks. They prefer a strong wage inflation response when the driving process is TFP and a weak response when the driving process is relative productivity.

6.5 Comparing Ramsey to Simple Rules

The Ramsey solution has the advantage of being second best. A planner with complete information, the ability to react to any economic variable, and technology to commit to the optimal rule is able to implement this policy that delivers the highest welfare given a set of welfare weights and frictions in the economy. In contrast, any simple interest rate rule must be weakly worse than the Ramsey interest rate, but has the advantages of responding to a short list of economic variables according to a linear rule. This section compares the globally optimal simple interest rate rule to the Ramsey interest rate rule. I use the welfare weight $\psi = s$ so the planner cares about each group equally. Searching over the same grid of parameter values as in the previous section gives $\rho = 0$, $\phi_\pi = 0.55$, $\phi_y = 0$ and $\phi_w = 1.95$. In other words, a strictly utilitarian planner chooses the same coefficients as one who cares only about the low-skilled group.

Next, I simulate the model under the optimal simple rule and the Ramsey rule and compare the impulse responses for the output gap, price inflation, and wage inflation in Figures 15-17 respectively. With the exception of the relative productivity shock, the impulse responses under each rule look very similar. This suggests that the Ramsey rule is well proxied by a simple rule that targets wage and price inflation. Indeed, comparing Figures 12-14 with 15-17 shows that the differences between the Ramsey rule and the optimal simple rule are often an order of magnitude smaller than the differences between the Ramsey rule and either strict rule. comparing the expected welfare under both rules produces a consumption equivalent of less than two one hundredths[8] of one percent of consumption.

The significance of the optimal simple interest rate rule extends beyond its strong overlap with the Ramsey rule. A large portion of the literature studying monetary policy in the New Keynesian tradition finds that a strong response to price inflation is necessary to maximize welfare. The Ramsey rule that maximizes a sum of utilities produces exactly this result. Hence, the results from maximizing the utility of a representative agent comes close to maximizing the population weighted sum of utilities of the two types of workers.

7 Conclusion

In this paper I document several empirical facts about high and low-skilled workers over the business cycle. Extending an otherwise standard staggered price and wage setting model by including two types of workers who reset their nominal wages with different probabilities successfully capture these facts. The probability of reseting wages is grounded in micro evidence that low-skilled workers reset their wages with lower frequency than high-skilled workers. In terms of normative implications on the prescriptions of optimal monetary policy, low-skilled workers prefer a relatively stronger response to wage inflation and a lower response to price inflation. At the same time, the quantitative magnitudes of the welfare losses from following one optimized rule under given welfare weights versus another optimized rule under different weights are very small.

One direction for future research is to extend this sort of model with borrowing constraints or other sorts of financial frictions. If workers' access to financial markets varies systematically with skill level, there could be some interesting dynamics and policy implications. Another direction is to adopt search frictions as in Gornemann et al. (2012) and determine how the response of unemployment deviations in the optimal policy changes with the welfare weights of the planner.

[8] Check later.

Data Appendix

All data comes from the CPS-MORG. The data files are downloaded from the NBER.[9] The years go from 1979-2013. Some variables change definitions over the years, so the first step is to make consistent definitions of all the variables.

The variables that stay consistent over the entire time period include:

1) Year
2) Interview month
3) Age
4) Gender
5) Race
6) Weight
7) Earnwt
8) Earnhre
9) Earnwke
10) Paidhre
11) uhourse
12) hourslw

The variables that I keep that have changing definitions include:

1) Occupation
2) Industry
3) Class of worker
4) Employment Status
5) Education

The occupation and industry codes are three digit SIC and later NAICS codes that are updated in the census. Since I don't run any regressions, I just put the observations under common industry and occupation variables. Before 1992, the relevant education variable is "gradeat", which documented the highest grade attended by a subject. There is a dummy variable "gradecp" which documents whether the subject finished the highest grade attended. After 1992, the education variable was changed to "grade92" which documents the highest grade completed. I classify anyone who has no completed the 12th grade or received a GED as "less than high school". Anyone who has completed exactly twelve years of education is classified as "hsgrad". Before 1992 anyone who completed between one and three years of college is classified as having some college. After 1992, anyone who has an associate's

[9] http://www.nber.org/morg/annual/

degree or has some college but no degree is classified as having some college. The variable is "somcol". Finally, anyone with four years or more in college before 1992 and anyone with at least a Bachelor's degree after 1992 is classified as being a college graduate. The variable is "colgr". Pursuant to the definitions in the paper, anyone in the "somcol" or "colgr" category is classified as highly educated.

I create consistent definitions of labor force over the period. A subject is classified as "Employed - at work", "Employed - absent", "Unemployed", or "Not in the labor force." For class of worker, a subject is classified as either "Private", "Government", "Self employed", or "Never works or works for Free".

I drop all workers between younger than 16 and older than 65. I also drop anyone whose labor force classification doesn't fit into one of the listed categories. I assign hours worked last week to usual hours if usual hours is missing. I drop anyone who reports to be employed but report 0 or missing usual hours and I drop anyone who reports to be employed but reports 0 or missing usual weekly earnings. I assign 0 usual hours to anyone who is unemployed or not in the labor force.

A quarter variable is constructed from the interview month variable. Following Autor et al. (2008), I replace top coded earnings with 1.5 times the top code. Earnings per hour equals earnings per week divided by usual hours.

All the quarterly averages of hours are weighted by the weight variable. Earnings per hour averages and medians are weighted either by the product of usual hours and weight or the earnwt variable.

One last note, the first time through I kept everyone in every class of worker. If I drop all self employed people and those who work for no pay, the quarterly variables barely change. The cyclical standard deviation of wages are the same out to three decimal places, so it really doesn't matter.

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	$\frac{std(x)}{std(gpd)}$	$\rho(y_t, x_t)$	$\rho(y_{t-1}, x_t)$	$\rho(y_{t+1}, x_t)$
$n_{s,t}$	0.804	0.728	0.811	0.592
$n_{u,t}$	1.355	0.818	0.871	0.665
$\bar{w}_{s,t}$	0.739	-0.106	-0.029	-0.204
$\bar{w}_{u,t}$	0.530	-0.249	-0.175	-0.230
$w_{s,t}^{med}$	0.8551	-0.026	0.033	-0.010
$w_{u,t}^{med}$	0.8333	-0.077	-0.093	-0.069

Table 1: These are summary statistics on labor market variables from 1979-2012. All variables are logged and then HP filered with a smoothing parameter of 1600.

parameter	interpretation	value
β	Discount factor	0.995
ψ	Bond holding cost	0.0001
γ	Risk aversion	1
χ	Frisch elasticity	1
s	Skilled share	0.4517
θ_s	disutility of labor - high-skilled	8.6804
θ_u	disutility of labor - low-skilled	14.8251
υ_s	elasticty of substitution - high-skilled	10
υ_u	elasticity of substitution - low-skilled	10
ϵ	elasticity of substitution - goods	10
ϕ	Price stickiness	0.67
ξ_s	Skilled wage stickiness	0.34
ξ_u	Unskilled wage stickiness	0.72
h	Skill share	0.6337
ρ_j	AR - All shocks	0.97
σ_a	standard deviation - TFP shock	0.0071
σ_ν	standard deviation - elaticity of substitution-workers	0.005
σ_ϵ	standard deviation - elaticity of substitution-goods	0.005
σ_h	standard deviation - skill share	0.005
ϕ_π	Response to price inflation	1.5
ϕ_y	Response to output gap	0
ϕ_w	Response to wage inflation	0
ρ_i	AR - nominal interest rate	0

Table 2: Model parameters

	Data	Model					
		baseline	$\xi_s = \xi_u = 0.54$	Just TFP	Alt 1	Alt 2	Alt 3
std(gdp)	0.0138	0.0138	0.0139	0.0124	0.0154	0.0111	0.0094
std(high-skilled hours)	0.0111	0.0078	0.0094	0.0030	0.0067	0.0061	0.0059
std(low-skilled hours)	0.0187	0.0143	0.0119	0.0056	0.0130	0.0127	0.0119
std(high-skilled wages)	0.0101	0.0101	0.0088	0.0080	0.0091	0.0095	0.0085
std(low-skilled wages)	0.0073	0.0073	0.0089	0.0054	0.0079	0.0074	0.0082
corr(gdp,shours)	0.7275	0.5597	0.6625	0.6930	0.3658	0.2711	0.0901
corr(gdp,uhours)	0.8176	0.5718	0.4376	0.9291	0.3918	0.3822	0.1705
corr(gdp,swages)	-0.1056	0.7246	0.6384	0.8326	0.7120	0.7563	0.7255
corr(gdp,uwages)	-0.2491	0.5780	0.6253	0.6501	0.5633	0.6800	0.6622

Table 3: These are results from the model. The second moments from the data are in the first column, results from the model under the basic calibration are in the second column. The third and fourth column show the results when the frequency of wage adjustment is the same for both groups and when there is just TFP shocks respectively. The monetary policy parameters are set to $\phi_\pi = 1.5, \phi_y = 0.125, \phi_w = 0; \phi_\pi = 1, \phi_y = 0, \phi_w = 0.5; \phi_\pi = 1, \phi_y = 0.125, \phi_w = 0.5$ in the fifth through seventh columns respectively.

	Ramsey	Strict Price	Strict Wage
std(ir_t)	0.0015	0.0041	0.0013
std(π_t^p)	0.0028	0.0021	0.0035
std(π_t^w)	0.0008	0.0023	0.0007
$\rho(ir_t \pi_t^p)$	0.7874	1	0.8747
$\rho(ir_t, \pi_t^w)$	-0.1733	-0.9144	1
$\rho(ir_t, y_t)$	-0.6100	-0.9144	-0.3817

Table 4: The first column contains the second moments when the model is simulated under the Ramsey interest rate rule. In the second column the policy rule is set so $\phi_w = 2$ and the other policy coefficients to 0. In the third column the policy rule is set so $\phi_\pi = 2$ and the other policy coefficients to 0.

Rule	λ_H	λ_L
$\phi_\pi = 1.2,\ \phi_y = 0,\ \phi_w = 0$	0.5726	0.5147
$\phi_\pi = 1.2,\ \phi_y = 0.125,\ \phi_w = 0$	4.7024	5.5908
$\phi_\pi = 5,\ \phi_y = 0,\ \phi_w = 0$	0.1620	0.2381
$\phi_\pi = 0,\ \phi_y = 0,\ \phi_w = 1.2$	0.2156	0.0188
$\phi_\pi = 0,\ \phi_y = 0.125,\ \phi_w = 1.2$	3.2043	3.6580
$\phi_\pi = 0,\ \phi_y = 0,\ \phi_w = 5$	0.1510	-0.0449
$\phi_\pi = 0.75,\ \phi_y = 0,\ \phi_w = 0.75$	0.1470	0.0016
$\phi_\pi = 0.75,\ \phi_y = 0.125,\ \phi_w = 0.75$	1.2794	1.2938

Table 5: This table contains the results from several stylized interest rate rules when $\rho = 0.\lambda_j$ is the consumption equivalent for someone in skill group j.

Rule	λ_H	λ_L
$\phi_\pi = 1.2,\ \phi_y = 0,\ \phi_w = 0$	0.2429	0.2039
$\phi_\pi = 1.2,\ \phi_y = 0.125,\ \phi_w = 0$	2.7200	3.1597
$\phi_\pi = 5,\ \phi_y = 0,\ \phi_w = 0$	0.1826	0.1825
$\phi_\pi = 0,\ \phi_y = 0,\ \phi_w = 1.2$	0.1500	0.0167
$\phi_\pi = 0,\ \phi_y = 0.125,\ \phi_w = 1.2$	2.0295	2.2607
$\phi_\pi = 0,\ \phi_y = 0,\ \phi_w = 5$	0.1576	-0.0582
$\phi_\pi = 0.75,\ \phi_y = 0,\ \phi_w = 0.75$	0.1179	0.0135
$\phi_\pi = 0.75,\ \phi_y = 0.125,\ \phi_w = 0.75$	0.9590	0.9442

Table 6: This table contains the results from several stylized interest rate rules when $\rho = 0.8.\lambda_j$ is the consumption equivalent for someone in skill group j.

ψ	ϕ_π	ϕ_w	ϕ_y	ρ	V	λ_H	λ_L
0	0.1750	2.0500	0	0	-549.78	0.1620	-0.0691
0.2	0.2750	2.0250	0	0	-524.46	0.1566	-0.0686
0.4	0.4250	1.9500	0	0	-499.14	0.1501	-0.0662
0.6	0.6500	1.9000	0	0	-473.82	0.1429	-0.0602
0.8	0.8000	1.2000	0	0.9	-448.46	0.1125	-0.0030
1	0.9750	0.7750	0	0.9	-423.10	0.1094	0.0173

Table 7: This table shows the globally optimal simple interest rate rule for a given set of welfare weights. λ_j is the consumption equivalent for skill group j.

		Different				Same			
	ψ	ϕ_π	ϕ_w	λ_H	λ_L	ϕ_π	ϕ_w	λ_H	λ_L
Baseline	0	0.20	2.00	0.1566	-0.0629	0.90	3.00	0.1341	-0.0242
	1	3.00	3.00	0.1273	-0.0169	0.40	1.20	0.1170	0.0158
$\xi_s = \xi_u = 0.53$	0	0	1.50	0.1048	0.0562	0.90	3.00	0.0533	0.0533
	1	3.00	3.00	0.0033	0.2082	0.90	3.00	0.0533	0.0533
Just TFP	0	1.40	3.00	0.0401	0.0183	1.00	3.00	0.0243	0.0243
	1	1.10	3.00	0.0396	0.0187	1.00	3.00	0.0243	0.0243
Just Relative Prod	0	3.00	0.30	0.0903	-0.0813	3.00	3.00	0.0950	-0.0648
	1	1.10	0.00	0.0470	-0.0232	1.10	0.00	0.0297	-0.0084
Just price markup	0	0.00	1.60	0.0441	-0.0256	0.50	0.60	0.0115	0.0110
	1	3.00	0.00	-0.0343	0.1742	0.60	3.00	0.0111	0.0111
Just Wage markup	0	0.50	3.00	0.0075	0.0020	0.70	3.00	0.0072	0.0032
	1	1.80	0.60	0.0072	0.0024	0.90	1.40	0.0067	0.0038

Table 8: This table contains the results from the robustness exercises. The results under the heading "different" are produced using the parameterization in Table 2. The results under the heading "same" are produced using the same parameterization except that $\xi_s = \xi_u = 0.53$.

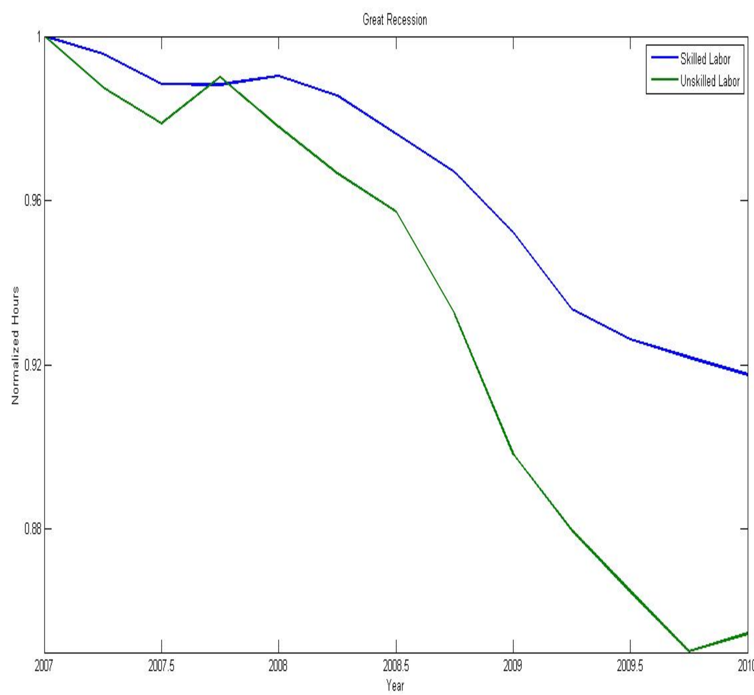

Figure 1: Usual hours worked per week. 2007 is normalized to 100.

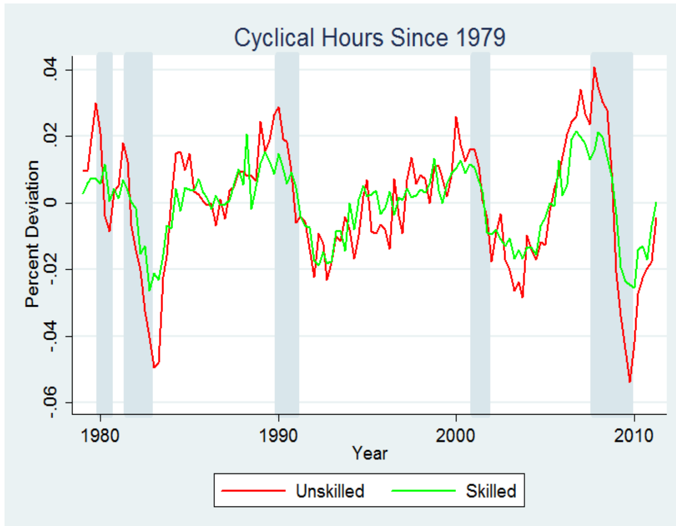

Figure 2: Usual hours worked per week from 1979-2012. Data is logged and HP filtered with a smoothing parameter of 1600.

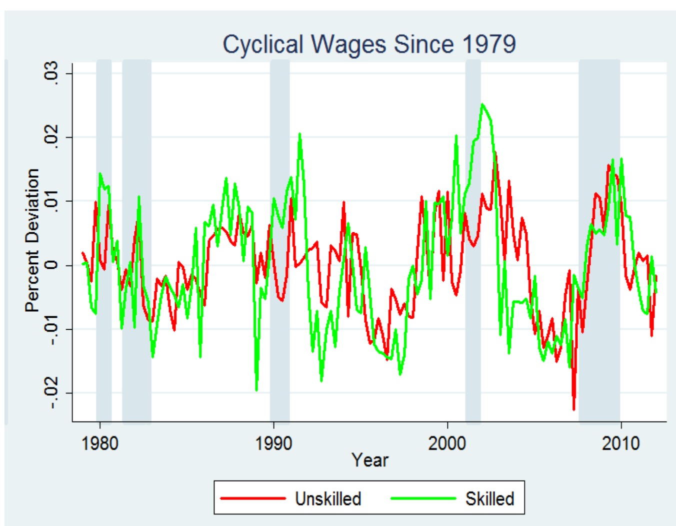

Figure 3: Compensation per hour from 1979-2012. Data is logged and HP filtered with a smoothing parameter of 1600.

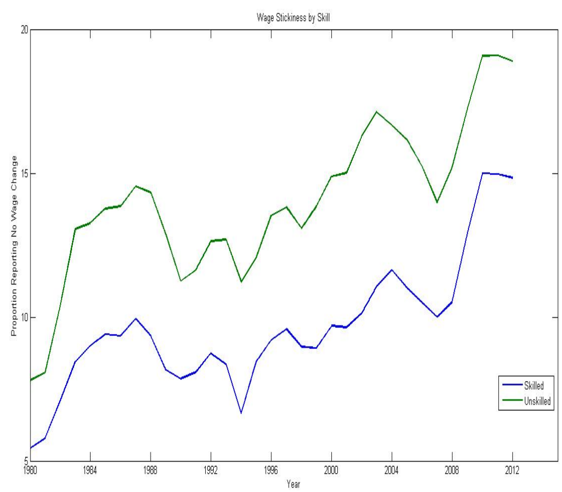

Figure 4: Probability that a worker's nominal wage does not change over one year. Data taken from http://www.frbsf.org/economic-research/nominal-wage-rigidity/

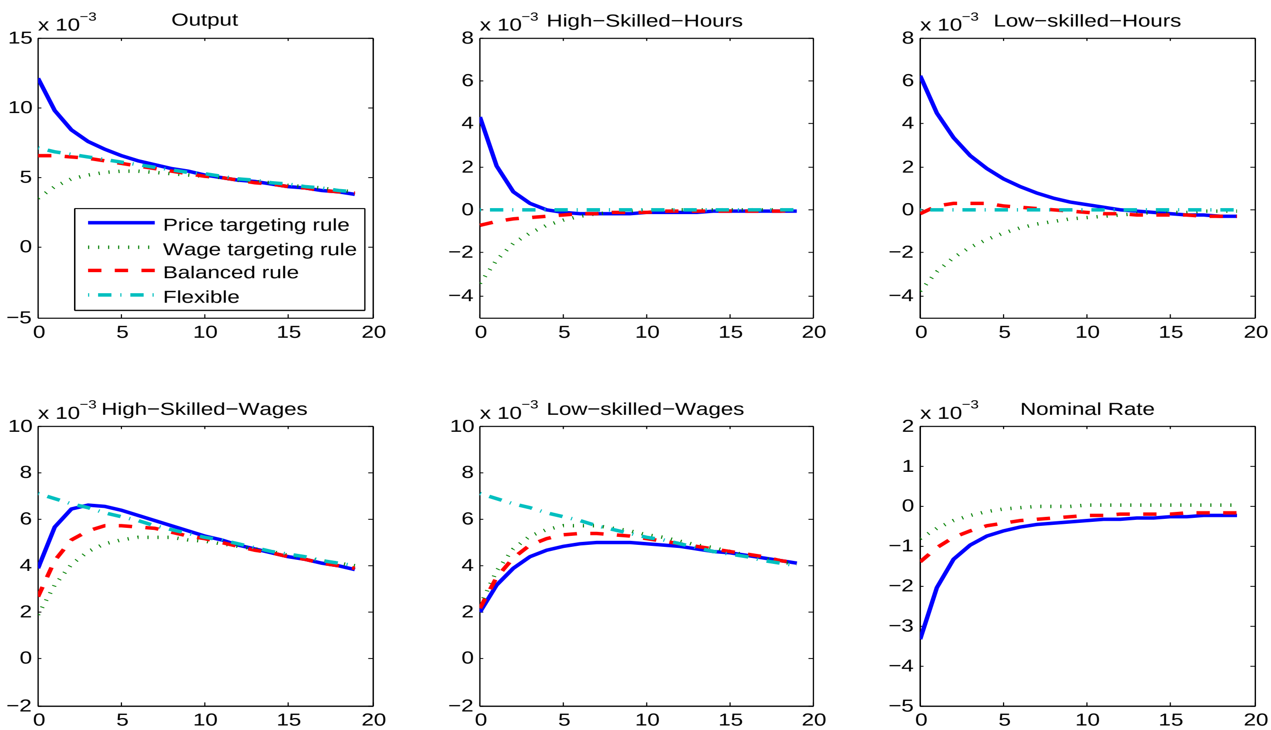

Figure 5: 20 period impulse response functions to a one standard deviation TFP shock.

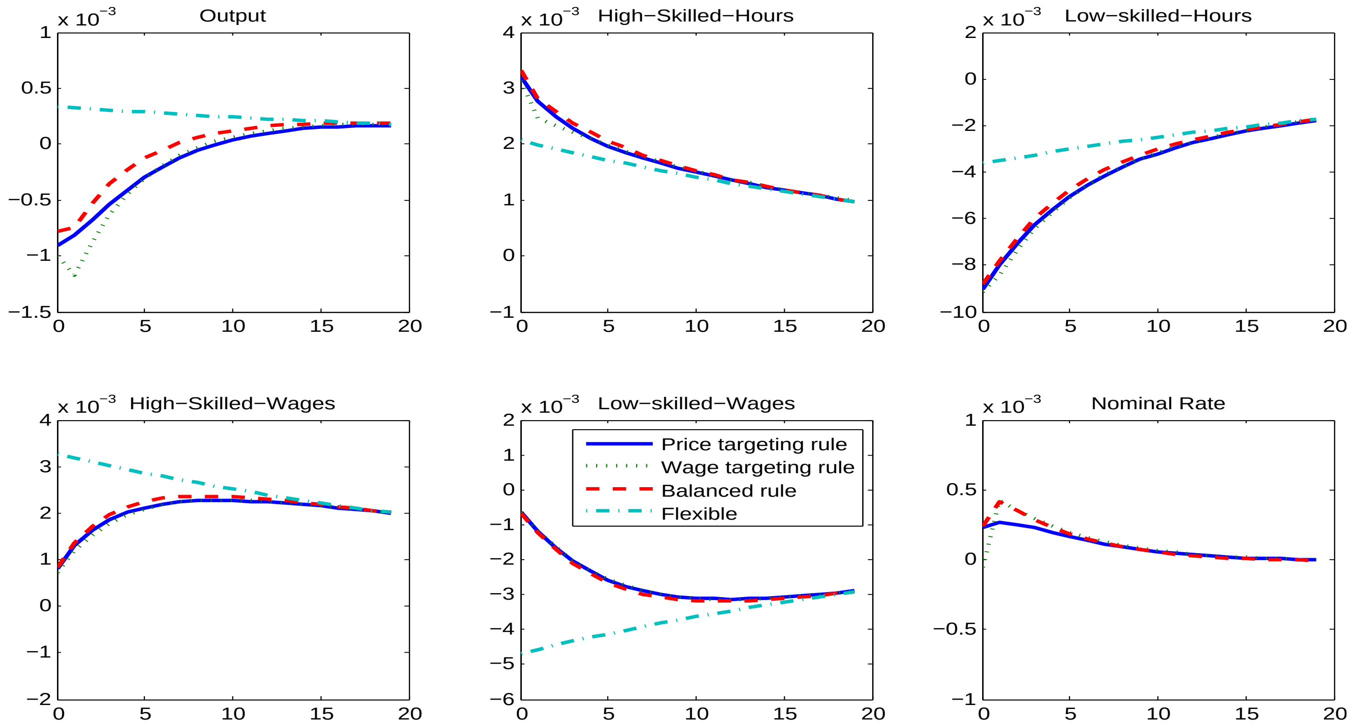

Figure 6: 20 period impulse response functions to a one standard deviation relative productivity shock.

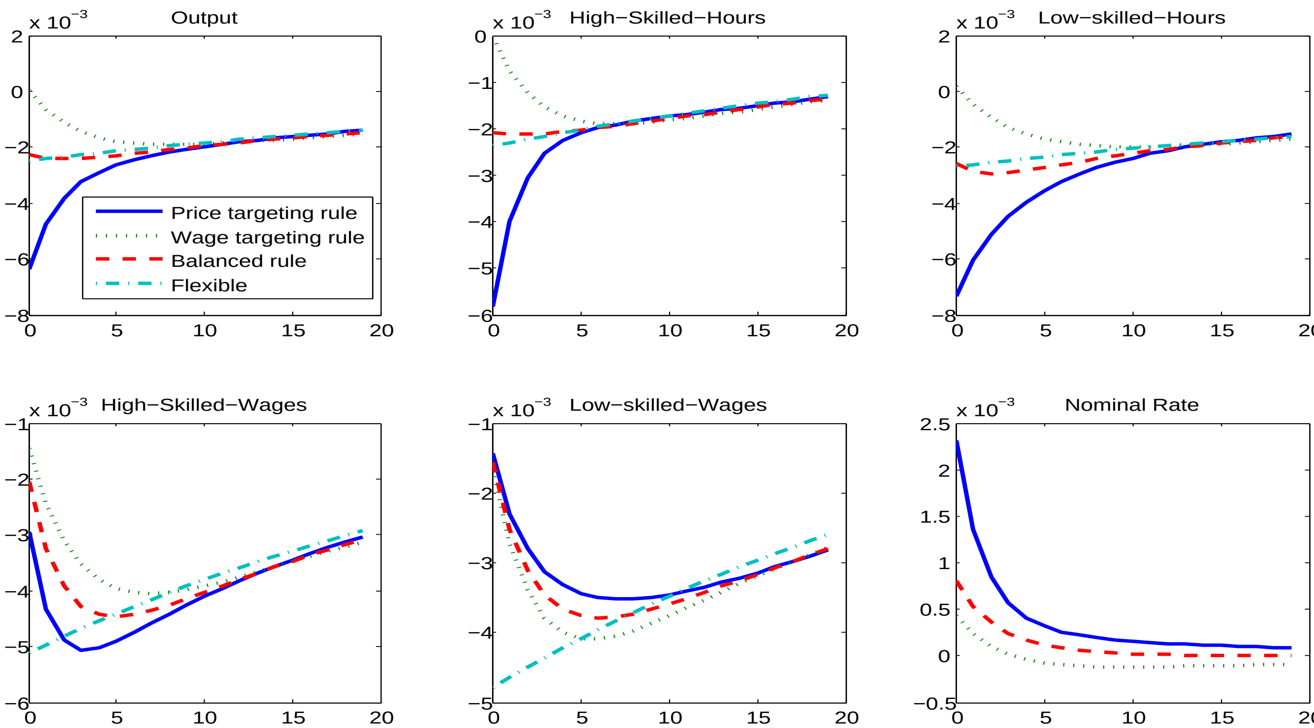

Figure 7: 20 period impulse response functions to a one standard deviation price markup shock.

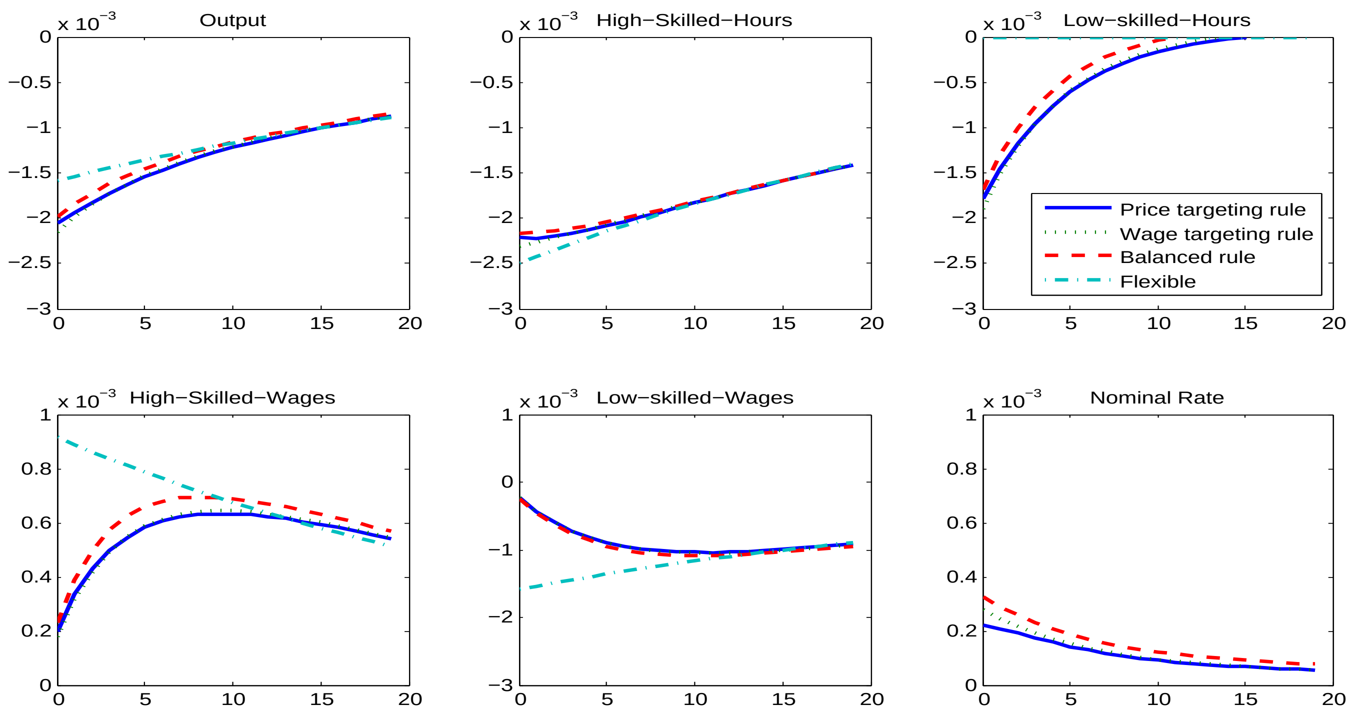

Figure 8: 20 period impulse response functions to a one standard deviation high-skill wage markup shock.

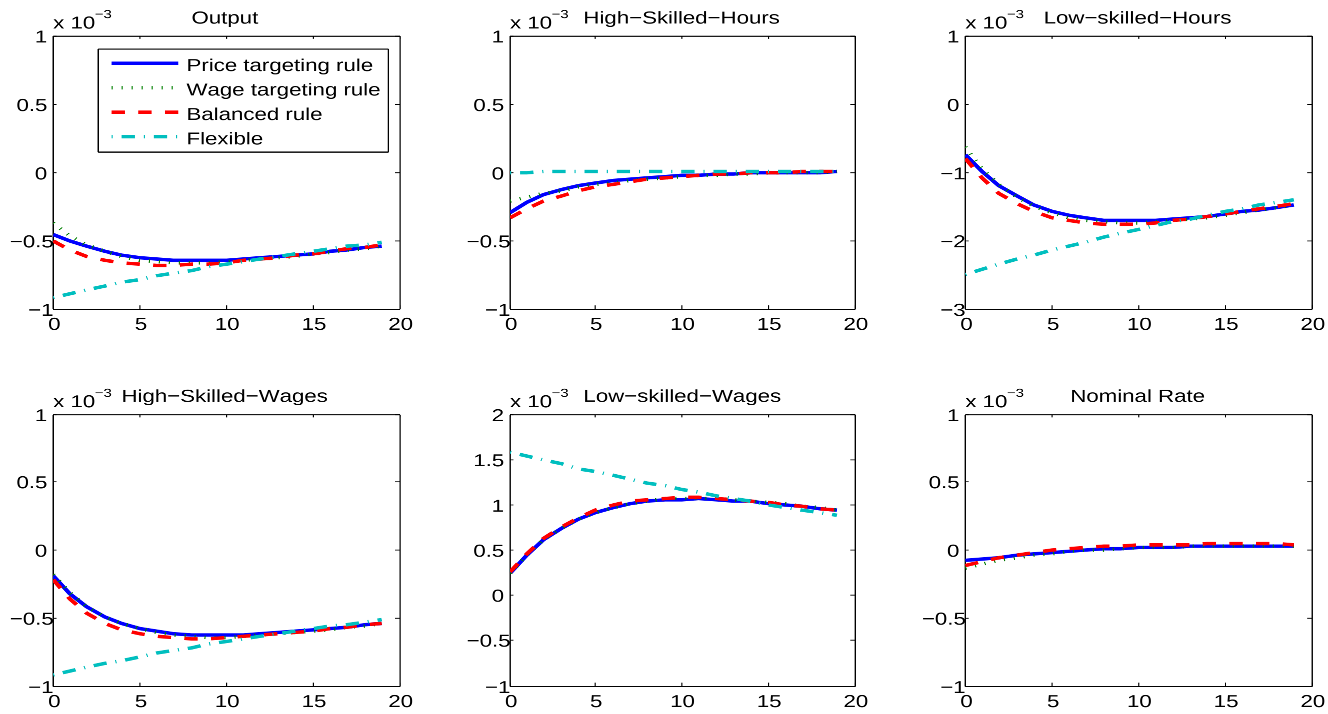

Figure 9: 20 period impulse response functions to a one standard deviation low-skill wage markup shock.

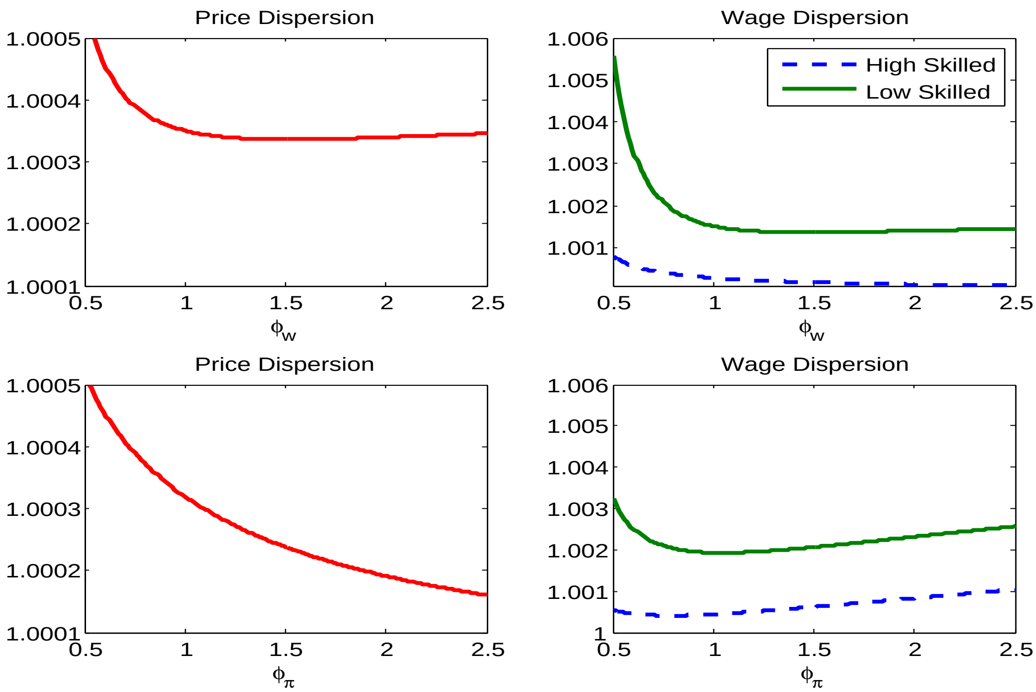

Figure 10: Mean price and wage dispersion (up to a second order approximation) as a function of the policy parameters. The other parameters in the policy rule are $\phi_y = 0, \rho = 0.5$.

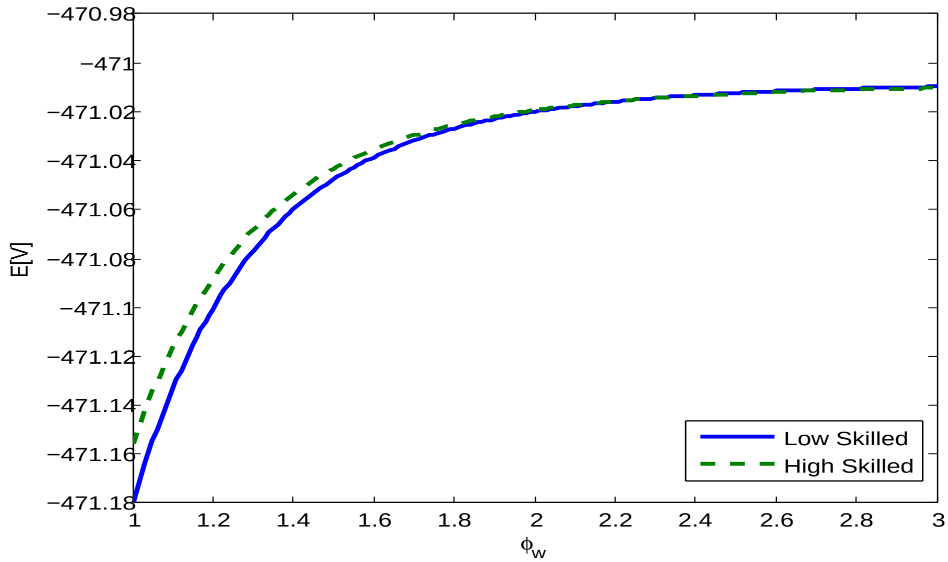

Figure 11: Unconditional expected value of lifetime utility for both groups. The only difference in parameters is in ξ_j, with $\xi_s = 0$ and $\xi_u = 0.9$. The other parameters in the policy rule are $\phi_\pi = 0.75, \phi_y = 0, \rho = 0.5$.

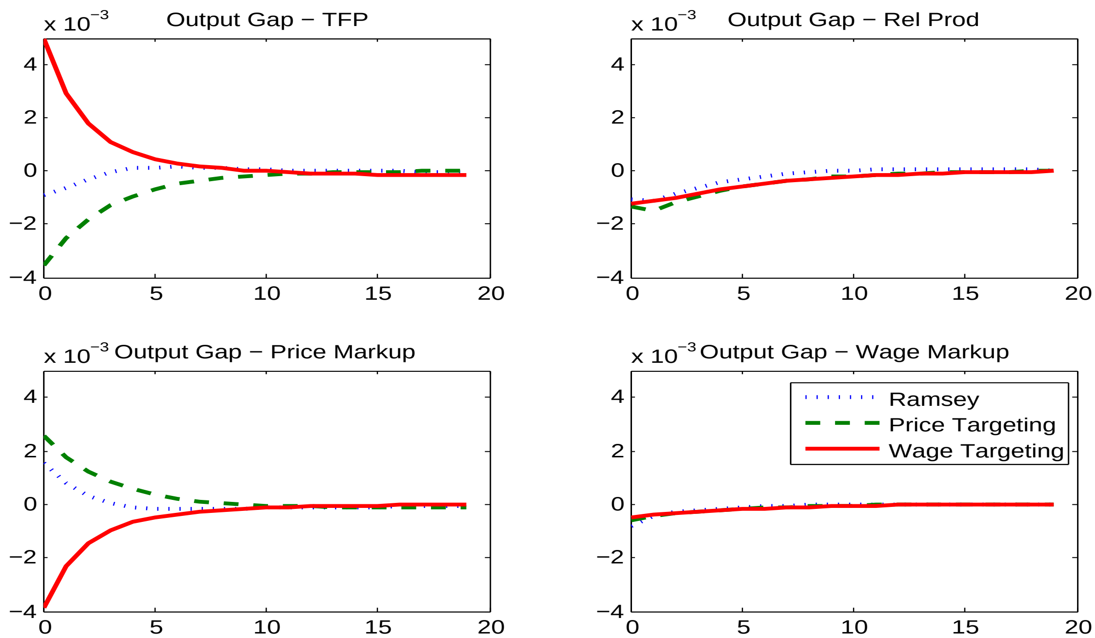

Figure 12: 20 period impulse response functions of the output gap to each shock comparing Ramsey rule to price and nominal wage targeting rules.

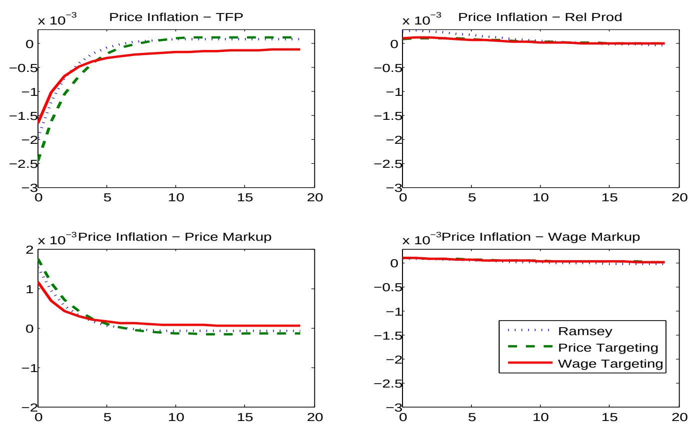

Figure 13: 20 period impulse response functions of price inflation to each shock comparing Ramsey rule to price and nominal wage targeting rules.

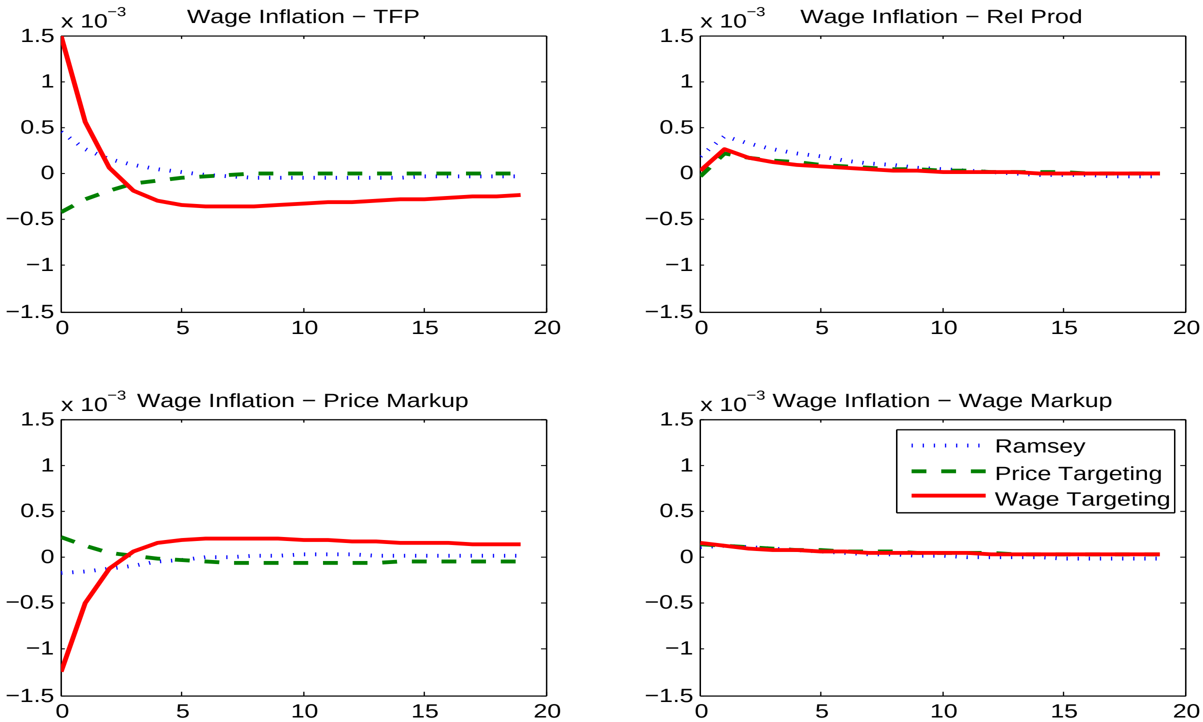

Figure 14: 20 period impulse response functions of wage inflation to each shock comparing Ramsey rule to price and nominal wage targeting rules.

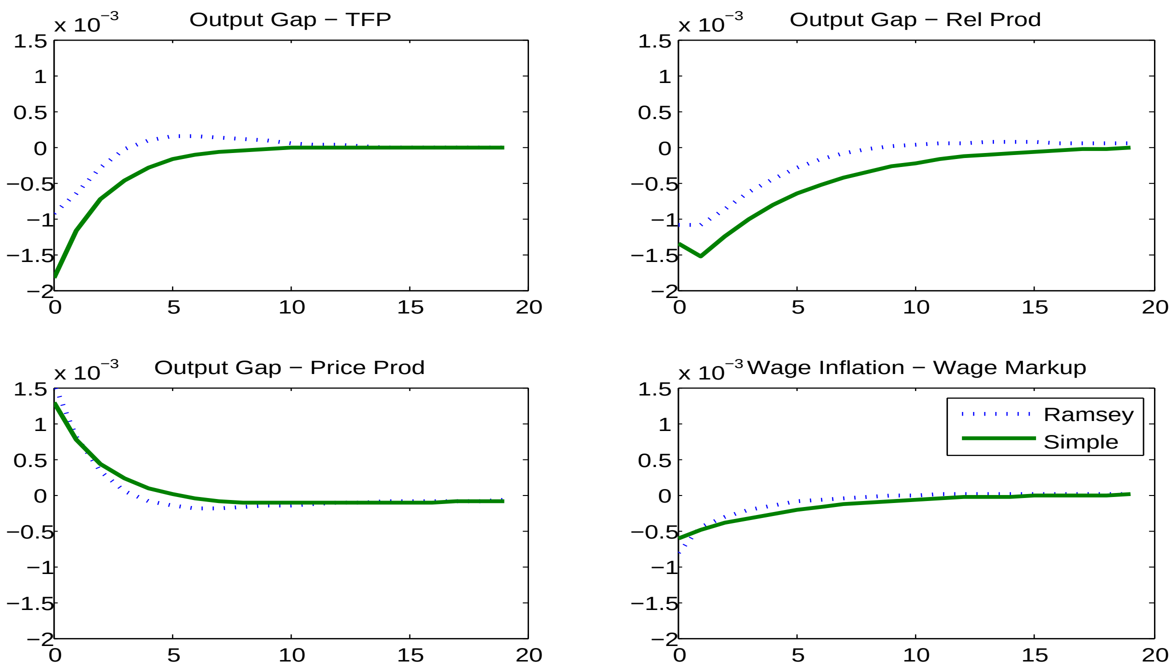

Figure 15: 20 period impulse response functions of the output gap to each shock comparing Ramsey rule to the nominal interest rate rule that maximizes the Utilitarian social welfare function with weights equal to each group's share in the population.

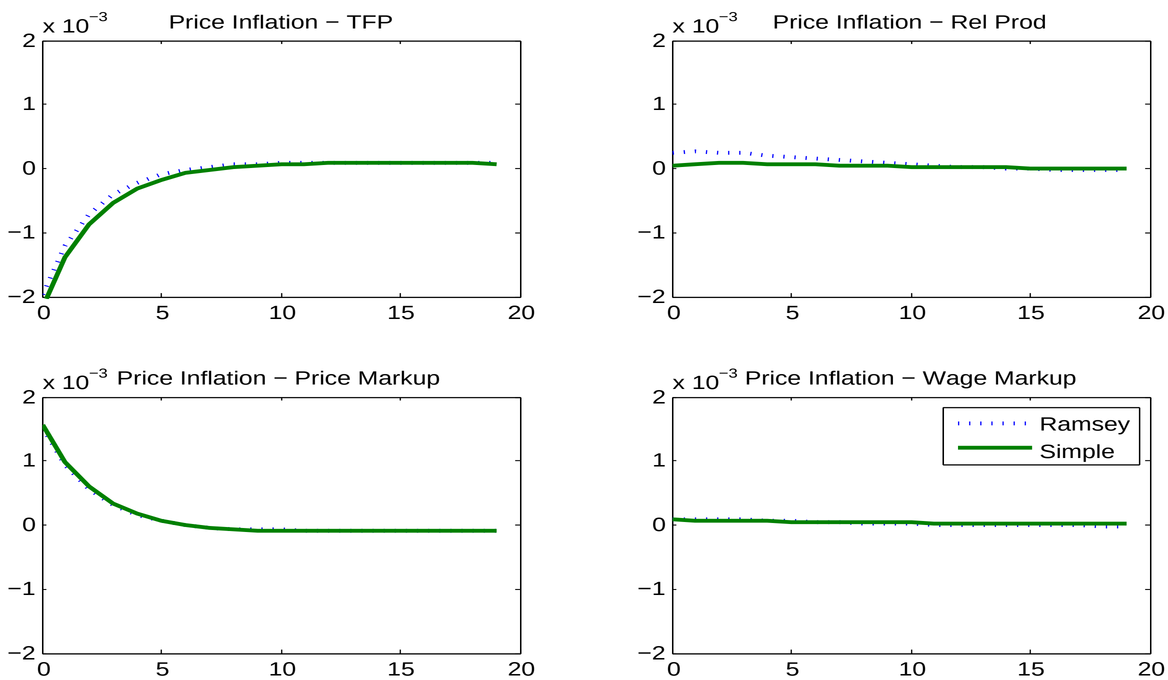

Figure 16: 20 period impulse response functions of price inflation to each shock comparing Ramsey rule to the nominal interest rate rule that maximizes the Utilitarian social welfare function with weights equal to each group's share in the population.

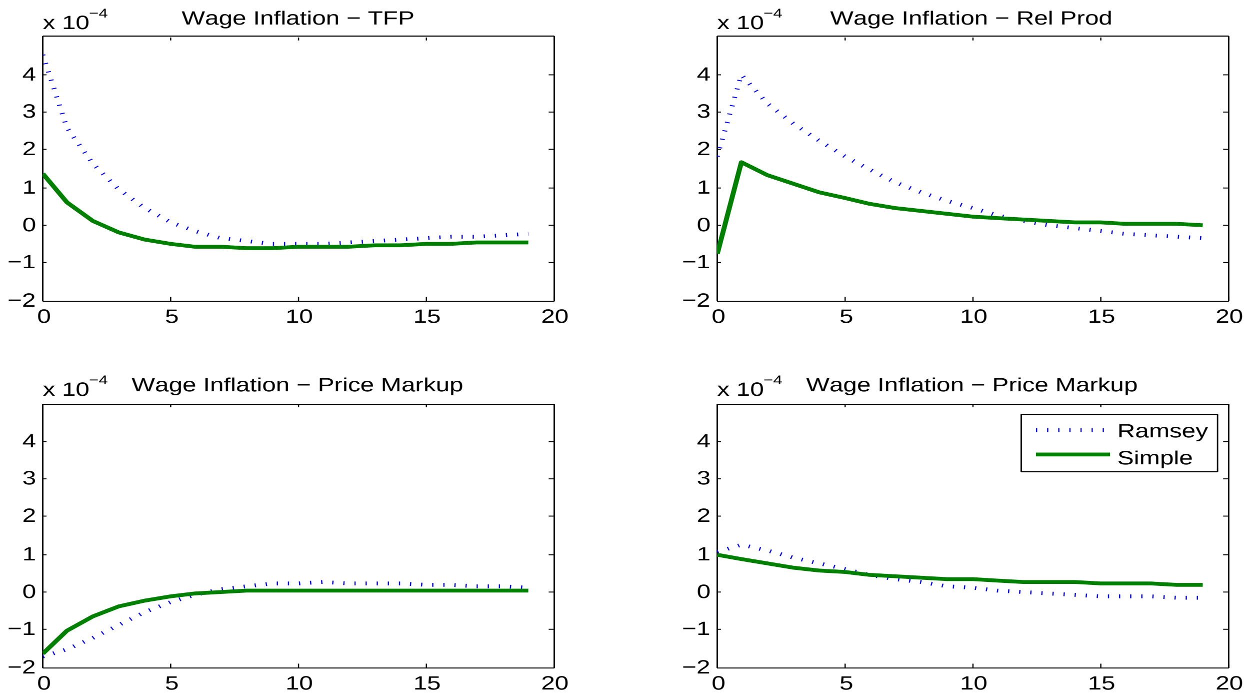

Figure 17: 20 period impulse response functions of wage inflation to each shock comparing Ramsey rule to the nominal interest rate rule that maximizes the Utilitarian social welfare function with weights equal to each group's share in the population.