Organizational Learning and Optimal Fiscal and Monetary Policy

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Abstract

In this paper we study optimal fiscal and monetary policy in a standard monetary Ramsey model augmented with price stickiness and organizational learning-by-doing (LBD) mechanism in production technology. Our main result is that optimal Ramsey inflation is very stable and persistent over the business cycle. While a dynamic link between current production and future productivity generates the inflation persistence, the real cost of price adjustment is the key for the very low volatility in optimal inflation. Both of these mechanisms work through the monopolistic firms’ optimal pricing condition – namely the New Keynesian Philips Curve. A second important result is that optimal tax policy is counter-cyclical – tax rates fall during recession and rise during boom. This finding contrasts with pro-cyclical tax results obtained in standard sticky price Ramsey models. The basic intuition for the result is that in presence of learning-by-doing, the Ramsey planner finds it relatively costly to raise taxes in response to a negative technology shock. Higher taxes would reduce hours, output, and hence organizational capital which will magnify the shock further by reducing future productivity. Therefore, the planner would optimally lower taxes to raise the after tax return to work and minimize the effects of the shock. Finally, inflation, nominal interest rate, and labor income tax rates are relatively lower in our model as compared to models without learning-by-doing. This result is a direct consequence of a relatively lower markup generated by the presence of learning-by-doing in our model.

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1. Introduction

Ramsey models featuring flexible-price environments (see Chari et al. (1991); Calvo and Guidotti (1993); Chari and Kehoe (1999)) find that optimal inflation is highly volatile and serially uncorrelated. The government has nominal, non-state-contingent liabilities outstanding and, under the Ramsey plan,
it uses surprise inflation as a lump-sum tax on financial wealth. Essentially, inflation plays the role of a shock absorber of unexpected innovations in the fiscal deficit. Similarly, in Ramsey models with nominal rigidities optimal inflation is still characterized by very little persistence even though it is very stable in such environments (see Schmitt-Grohé and Uribe (2004b); Siu (2004)). The fact that very little or no persistence results emerges with optimal Ramsey inflation in the literature motivated Chugh (2007) to answer the question originally raised by Chari and Kehoe (1999) - whether there are any general equilibrium settings which can rationalize inflation persistence as part of the Ramsey policy. Chugh (2007) introduces capital and habit persistence in preferences in a otherwise standard flexible-price Ramsey model and finds that optimal inflation is substantially persistent and highly volatile - even more volatile than the standard flexible-price Ramsey models would suggest.

As the above discussion hints it has proven difficult to find Ramsey models where optimal inflation is both persistent and stable. The main contribution of this paper is to address this issue by proposing a Ramsey model where optimal inflation has these two properties. In particular, we extend a standard cash-credit good monetary Ramsey model by adding price stickiness and organizational learning-by-doing (LBD) mechanism in the production technology. By delivering a crucial result – optimal inflation is characterized by substantial persistence and very low volatility – our model fills an important gap in the Ramsey literature.

The basic mechanism regarding organizational learning and knowledge accumulation is that organizations learn from their production process and accumulate this firm-specific knowledge — known as organizational capital — that raises future productivity$^{1,2}$. One critical feature of this knowledge is that it is produced jointly with output and embodied in the organization itself. To model organizational learning and knowledge accumulation we follow Cooper and Johri (2002) and introduce a firm-level learning-by-doing effect into the production technology$^{3}$. In particular, production in any particular period by a firm leads to the accumulation of organizational capital by the firm. This causes increases not only in productivity in the next period but also in the stock of organizational capital in all future periods. To introduce nominal price rigidity we follow Rotemberg (1982) and assume that firms incur quadratic costs in adjusting their nominal prices.

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$^{1}$Atkeson and Kehoe (2005) note “… At least as far back as Marshall (1930, bk. iv, chap. 13.1), economists have argued that organizations store and accumulate knowledge that affects their technology of production. This accumulated knowledge is a type of unmeasured capital distinct from the concepts of physical or human capital in the standard growth model…..”

$^{2}$Organizational learning and knowledge accumulation has long been considered significant too (see Atkeson and Kehoe (2005); Cooper and Johri (2002); Prescott and Visscher (1980); Rosen (1972); Arrow (1962) and many others ). In particular, Atkeson and Kehoe (2005) model and estimate the size of organizational capital for the US manufacturing sector and find that it has a value of roughly 66 percent of physical capital.

$^{3}$This particular theme of modeling organizational capital has a long tradition. Rosen (1972); Ericson and Pakes (1995); Atkeson and Kehoe (2005) and many others have developed models in which organization capital is acquired by endogenous learning by doing.
Our result of stable and persistence Ramsey inflation depends on both learning-by-doing and price stickiness. While learning-by-doing mainly generates the persistence in optimal inflation, price rigidity generates the stability in it. Both of these mechanisms work through the intermediate firms’ optimal pricing condition – namely the New Keynesian Philips Curve. Learning-by-doing influences inflation persistence by introducing a dynamic consideration in the firms’ price setting decision. A current price change not only affects revenue and production today, it also affects knowledge accumulation, productivity, costs and hence profits in all future periods. This dynamic link between current price changes and future productivity induces the Ramsey planner to use the inflation in a more persistent manner. To make it more intuitive, suppose there is an inflation defined by a price increase this period. Given that monopolistic firms face downward sloping demand curves for their products, they now have to cut production to match the lower demands. Lower production this period causes lower accumulation of production knowledge which raises costs in the next period by lowering the productivity. Facing higher marginal costs in the next period, the monopolistic firms set relatively higher prices (which causes inflation again) in the next period as compared to environments without learning-by-doing. By parallel arguments, lower prices (deflation) this period will induce firms to set relatively lower prices in the next period as well. In Chugh (2007), persistence in optimal inflation is generated through a very different mechanism. His result depends on consumption-smoothing. With capital and habit, the ability to and the preference for consumption-smoothing is enhanced significantly. This generates a persistent real interest rate which implies persistent inflation through the Fisher relationship.

Although, learning-by-doing generates persistence in optimal inflation it can not reduce inflation volatility by itself. If prices are flexible, there is no real resource cost of price adjustment and the Ramsey planner still finds it optimal to use inflation to generate state-contingent returns from nominal risk-free government bonds. When price adjustment costs are introduced in the model, the planner faces a trade-off. On the one hand, the Ramsey planner would like to use surprise inflation because it serves as a non-distortionary instrument to finance innovations in the government budget and this is preferred to changes in distorting proportional labor income tax. On the other hand, the Ramsey planner has strong incentives to stabilize inflation to minimize the costs associated with inflation changes. As Schmitt-Grohé and Uribe (2004b), and Siu (2004) find, even with a very small degree of price stickiness, this trade-off is overwhelmingly resolved in favor of inflation stability. When price stickiness is introduced into a LBD model the inflation persistence increases further as compared to a LBD model with flexible prices. The main reason for this is that in a model with both LBD and price stickiness, the inflation directly depends on past, present, and future values of some variables through the New Keynesian Philips Curve. This generates some extra smoothness in the optimal inflation path.

Another interesting result in our work is that optimal tax policy is counter-cyclical - tax rates fall during recessions. This finding contrasts with pro-cyclical tax results obtained in standard sticky price Ramsey models (see Chugh (2006); Schmitt-Grohé and Uribe (2004b)). The basic intuition for the re-
sult is that in presence of learning-by-doing, the Ramsey planner finds it relatively costly to raise the taxes in response to a negative technology shock. Higher taxes would reduce hours, output, and hence organizational capital which will magnify the shock further. Therefore, the planner would optimally lower taxes to raise the after tax return to work and minimize the effects of the shock. In a standard model without LBD, the planner does not face this dynamic shock amplifying effect of a higher tax and optimally increases the tax rate in a recession to finance exogenous government spending.

Finally, average inflation, nominal interest rate, and labor income tax rates are relatively lower in our model as compared to models without learning-by-doing. This result is consistent with Schmitt-Grohé and Uribe (2004b), and Chugh (2006) results that inflation, nominal interest rate, and labor income tax rates increase with market power. Schmitt-Grohé and Uribe (2004a), and Schmitt-Grohé and Uribe (2004b) explain that monopoly profits represent pure rents for the owners of the monopoly power. Ideally, the Ramsey planner would like to tax these rents at 100 percent rate because it would be non-distortionary. If profit taxes are unavailable or restricted to be less than 100%, the Ramsey planner uses the nominal interest rate as an indirect tax on profits. As the markup (market power) increases, the profit share increases and the Ramsey planner needs a higher nominal interest rate to tax these larger profits. Inflation increases with markup because on average inflation has a direct relationship with nominal interest rate through the Fisher relation. The labor income tax base falls as the economy becomes less competitive and the Ramsey planner needs to increase labor income tax rate when the markup goes up. The presence of learning-by-doing decreases the markup and hence the monopoly profit which calls for relatively lower inflation, nominal interest and labor income tax.

The remainder of the paper is organized as follows. The next section presents and describes the model while section 3 discusses about parameterizations and functional forms. Section 4 analyzes both steady-state and dynamic properties of Ramsey allocations and section 5 concludes.

2. The model

The model economy involves a large number of households and final good firms, a continuum of intermediate good producing firms, and the government. The structure of the economy is a standard growth model augmented with five frictions - monopolistic competition in the product market, learning-by-doing in the technological environment, sticky prices, a money demand by households, and distortionary labor income taxation. The intermediate goods producing firms possess a degree of monopoly power and hence, can earn positive economic profits. As owners of all the firms, households receive profits as dividends. However, the crucial features of the model economy that serve as the basis of our results are the firm-level learning-by-doing mechanism in the production technology and a quadratic cost of price-adjustment. The uncertainty in the economy is generated from two sources - stochastic productivity and government spending. We characterize, in turn, the economic environments faced by the households, the firms, and the government.
2.1. Households

The economy is populated by a large number of identical, infinitely lived households. Household’s preferences are defined over processes of consumption and leisure. Money demand is motivated by a standard cash-credit goods environment. Household has to spend cash to purchase a subset of consumption goods. The representative household’s objective function is given by,

\[ E_0 \sum_{t=0}^{\infty} \beta^t u(c_{1t}, c_{2t}, n_t), \]

where, \( c_{1t} \) denotes consumption of cash goods, \( c_{2t} \) denotes consumption of credit goods, \( n_t \) denotes fraction of household’s unit time endowment devoted to labor, \( \beta \in (0, 1) \) denotes the subjective discount factor, and \( E_0 \) denotes the mathematical expectation operator conditional on information available in period 0.

The household faces two sequences of constraints. The flow budget constraint in period \( t \) is given by

\[
\frac{M_t}{P_{t-1}} + \frac{B_t}{P_{t-1}} = (1 - \tau_{n}^{t-1}) w_{t-1} n_{t-1} + R_{t-1} \frac{B_{t-1}}{P_{t-1}} + \frac{M_{t-1}}{P_{t-1}} - c_{1t-1} - c_{2t-1} + p r_{t-1},
\]

where \( M_t \) is the nominal money held at the end of securities-market trading in period \( t \), \( B_t \) is the nominal, risk-free one-period bond held at the end of securities-market trading in period \( t \), \( R_t \) is the gross nominal interest rate on these bonds, and \( P_t \) is the nominal price. \( w_t \) is the real wage rate and subject to a proportional tax rate \( \tau_{n}^t \). As the owner of the firms the household receives profit, \( pr_t \), on a lump-sum basis with a one-period lag. We follow the same timing convention used in standard cash-credit goods environments\(^4\).\(^5\). At the start of period \( t \), after observing the shocks, households trade money and assets in a centralized securities market. This trading is followed by simultaneous trading in the goods-markets and the factor market. The household sells labor \( n_t \) and buys cash and credit goods. Purchases of the cash good are subject to a cash-in-advance constraint

\[ c_{1t} \leq \frac{M_t}{P_t}. \]

Purchases of the cash good are settled at the end of period \( t \), while purchases of the credit goods and selling of the labor service are settled at the beginning of period \( t + 1 \).

Let \( \lambda_t \) and \( \phi_t \) denote the Lagrange multipliers on the flow budget constraint and the cash-in-advance constraint respectively. Then the first-order conditions of the household’s maximization problem are

\(^4\)This particular timing convention is due to Lucas and Stokey (1983), and Chari et al. (1991)

\(^5\)Chugh (2009) demonstrates that the precise timing of financial markets and goods markets in a cash good-credit good model does not matter for the main baseline results in the Ramsey literature on optimal fiscal and monetary policy
(2)-(3) holding with equality and

\[ c_{1t} : \quad u_{1t} - \phi_t - \beta E_t \lambda_{t+1} = 0, \] (4)

\[ c_{2t} : \quad u_{2t} - \beta E_t \lambda_{t+1} = 0, \] (5)

\[ n_t : \quad -u_{3t} + \beta E_t [\lambda_{t+1} (1 - \tau^n_t) w_t] = 0, \] (6)

\[ M_t : \quad -\frac{\lambda_t}{P_{t-1}} + \frac{\phi_t}{P_t} + \beta E_t \frac{\lambda_{t+1}}{P_t} = 0, \] (7)

\[ B_t : \quad -\frac{\lambda_t}{P_{t-1}} + \beta E_t \frac{R_t \lambda_{t+1}}{P_t} = 0, \] (8)

where \( u_{1t} \) denotes the value of marginal utility of cash good in period \( t \) (similarly for \( u_{2t} \)), and \( u_{3t} \) denotes the value of marginal utility of labor in period \( t \).

Equation (8) gives rise to a standard Fisher equation,

\[ 1 = R_t E_t \left[ \frac{\beta \lambda_{t+1}}{\lambda_t} \frac{1}{\pi_t} \right], \] (9)

where \( \pi_t = \frac{P_t}{P_{t-1}} \), is the gross inflation rate between period \( t-1 \) and period \( t \). Combining (9) with (4) and (7) we can express the Fisher relation in terms of marginal utilities,

\[ 1 = R_t E_t \left[ \frac{\beta u_{1t+1}}{u_{1t}} \frac{1}{\pi_{t+1}} \right], \] (10)

which gives us the pricing formula for a one-period risk-free nominal bond. Denoting the nominal pricing kernel between period \( t \) and \( t+1 \) as \( Q_{t+1} \), we can write

\[ Q_{t+1} = \left( \frac{\beta u_{1t+1}}{u_{1t}} \frac{1}{\pi_{t+1}} \right), \] (11)

which implies the real pricing kernel as

\[ q_{t+1} = Q_{t+1} \pi_{t+1}. \] (12)

Combination of (4), (5), (7) and (8) implies a relationship between the gross nominal interest rate and the marginal rate of substitution between cash and credit goods

\[ R_t = \frac{u_{1t}}{u_{2t}}. \] (13)

Finally, combining equations (5) and (6), we obtain

\[ \frac{u_{3t}}{u_{2t}} = (1 - \tau^n_t) w_t. \] (14)

Equation (14) gives the optimal labor-leisure choice. It states that the presence of a non-zero labor income tax rate drives a wedge between the marginal rate of substitution between leisure-consumption and the real wage. Equation (13) states that a non-zero nominal interest rate drives a wedge between the marginal rate of substitution between cash-credit good consumption and the marginal rate of transformation between them, which is unity.
2.2. Production

The production environment consists of two sectors: an intermediate goods sector that produces differentiated goods using labor and organizational capital, and a final goods sector that uses intermediate goods to produce a unique final good. The two sector feature of the production environment is a standard convention in New Keynesian models. However, a novel feature of our model is the presence of a learning-by-doing mechanism in the production technology of the intermediate goods firms.

2.2.1. Final Goods Producers

Government consumption goods, cash consumption goods, and credit consumption goods are physically indistinguishable. There are a large number of producers who produce this unique final good in a perfectly-competitive environment. Final goods producers require only the differentiated intermediate goods as inputs and use the following CES technology for converting intermediate goods into final goods.

\[ y_t = \left[ \int_0^1 y_{it}^{\eta-1} di \right]^{\frac{\eta}{\eta-1}}, \]  

(15)

where \( \eta > 1 \) denotes the intratemporal elasticity of substitution across different varieties of consumption goods, and differentiated intermediate goods are indexed by \( i \in [0,1] \).

Each period final goods firms choose inputs \( y_{it} \) for all \( i \in [0,1] \) and output \( y_t \) to maximize profits given by

\[ P_t y_t - \int_0^1 P_{it} y_{it} di \]  

subject to (15). Here \( P_t \) denotes the nominal price of the final good and \( P_{it} \) denotes the nominal price of the intermediate good \( i \). The solution to this problem yields the input demand functions

\[ y_{it} = \left( \frac{P_{it}}{P_t} \right)^{-\eta} (y_t). \]  

(17)

2.2.2. Intermediate Goods Producers

There is a continuum of intermediate goods producers, indexed by the letter \( i \), who operate in a Dixit-Stiglitz style imperfectly competitive economy. Each of these firms produces a single variety \( i \) using two factor inputs - organizational capital, \( h_{it} \), and labor services, \( n_{it} \). The production technology of each firm \( i \) is given by

\[ y_{it} = z_t F(h_{it}, n_{it}), \]

where \( y_{it} \) is the intermediate good variety produced by firm \( i \). The variable \( z_t \) denotes an aggregate, exogenous, and stochastic productivity shock. The function \( F \) is assumed to be concave, and strictly increasing in two arguments. The stock of organizational capital is predetermined in the sense that \( h_{it} \) reflects the stock of organizational capital chosen at time \( t - 1 \). As in Cooper and Johri (2002)\(^6\), we

\[^6\text{Cooper and Johri (2002) offers a detailed justification for the modelling assumptions and presents a number of estimates of the learning technology at different levels of aggregation for the US economy.}\]
assume that the production technology has the following specific functional form:

\[ y_{it} = z_{it} n_{it}^{\alpha} h_{it}^{\theta} \]  

(18)

A key innovation in this paper is the presence of the organizational capital in the production technology of intermediate goods firms. Organizational capital refers to the stock of firm-specific knowledge which is jointly produced with output and embodied in the organization itself.\(^7\)\(^8\) Organizational capital is acquired by endogenous learning by doing. In other words, firms accumulate the stock of organizational capital through the process of past productions regarding how best to organize its production activities and deploy the optimal mix of inputs. In this model we assume that organizational capital is accumulated according to:

\[ h_{i,t+1} = (1 - \delta)^{h_{it}} h_{it} + h_{it}^{\gamma} y_{it}, \]  

(19)

where \(\delta\) is the depreciation rate of organizational capital and \(0 < \delta < 1, \gamma < 1\). This accumulation equation might be viewed as a technology that uses the existing stock of organizational capital and current plant output as productive inputs for the production of future organizational capital. All producers begin life with a positive and identical endowment of organizational capital. The restriction \(0 < \delta < 1\) is consistent with the empirical evidence supporting the hypothesis of organizational forgetting.\(^9\) This Cooper and Johri (2002) framework of how learning-by-doing leads to productivity increases is not particularly new in the literature. Rosen (1972), Prescott and Visscher (1980), Bahk and Gort (1993), Irwin and Klenow (1994), Jarmin (1994), Ericson and Pakes (1995), Benkard (2000), Thornton and Thompson (2001), Atkeson and Kehoe (2005) and many others have developed and tested models in which organization capital is acquired by endogenous learning-by-doing.

Prices are assumed to be sticky à la Rotemberg (1982). Specifically, in changing their prices intermediate goods firms face a real resource cost which is quadratic in the inflation rate of the good it produces.

\[ \varphi \left( \frac{P_{it}}{P_{it-1}} - \pi \right)^2. \]  

(20)

The parameter \(\varphi\) measures the degree of price stickiness. The higher is \(\varphi\), the more sluggish is the

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\(^7\)In defining organizational capital Prescott and Visscher (1980) write: “The manner in which information is accumulated in the firm offers an explanation for the firm’s existence. Information is an asset to the firm, for it affects the production possibility set and is produced jointly with output. We call this asset of the firm its organization capital....”

\(^8\)Similarly, Lev and Radhakrishnan (2005) note, “Organization capital is thus an agglomeration of technologies, business practices, processes and designs, including incentive and compensation systems, that enable some firms to consistently extract out of a given level of resources a higher level of product and at lower cost than other firms”.

\(^9\)Organizational forgetting is the hypothesis that a firm’s stock of production experience depreciates over time. Argote et al. (1990) provide empirical evidence for the hypothesis of organizational forgetting associated with the construction of Liberty Ships during World War II. Similarly, Darr et al. (1995) provide evidence for this hypothesis for pizza franchises and Benkard (2000) provide evidence for organizational forgetting associated with the production of commercial aircraft.
adjustment of nominal prices. Price are fully flexible if $\varphi$ equals zero. The parameter $\pi$ denotes the steady state inflation rate.

We assume that the firm must satisfy demand at the posted price. That is, every firm $i$ faces the following constraint:

$$y_{it} \geq \left( \frac{P_{it}}{P_t} \right)^{-\eta} y_t.$$

The intermediate firm takes aggregate demand $y_t$ and the aggregate price level $P_t$ as given. Therefore, the decision problem of the representative firm $i$ is to choose the plans for $n_{it}$, $h_{it+1}$, and $P_{it}$ so as to maximize the present discounted value of lifetime profits:

$$\sum_{t=0}^{\infty} Q_t P_t \left\{ P_{it} - w_t n_{it} - \frac{\varphi}{2} \left( \frac{P_{it}}{P_{t-1}} - \pi \right) \right\}$$

subject to (18), (19), and (21). Here $Q_t$ is the consumer’s stochastic discount factor which is given by equation (11). As households own all the intermediate firms and thus receive their profits, it is appropriate to use their nominal discount factor in pricing revenue and costs in adjoining periods.

Let $P_t \Psi_{it}$ and $P_t mc_{it}$ be the Lagrange multipliers associated with the constraints (19) and (21) respectively. Then the first-order conditions of the firm’s maximization problem with respect to labor and organizational capital are, respectively,

$$n_{it} : \quad w_t = mc_{it} \frac{y_{it}}{n_{it}} \quad \text{(22)}$$

$$h_{it+1} : \quad \Psi_{it} = E_t Q_{t+1} \pi_{t+1} mc_{it+1} \left[ \frac{y_{it+1}}{h_{it+1}} + \Psi_{it+1} \left\{ (1 - \delta^h) + \gamma h_{it+1} y_{it+1} \right\} \right]. \quad \text{(23)}$$

Lagrange multiplier $mc_{it}$ has the interpretation of marginal costs. This can be seen more clearly if we rearrange (22) as,

$$mc_{it} = \frac{w_t}{z_{F_n}(h_t, n_t)}. \quad \text{(24)}$$

Given all else the same, a larger stock of organizational capital, $h_t$, implies a lower marginal cost, $mc_t$.

The first order condition with respect to $P_{it}$ yields a New Keynesian Phillips Curve,

$$(1 - \eta) \left( \frac{P_{it}}{P_t} \right)^{-\eta} y_t + mc_{it} \eta \left( \frac{P_{it}}{P_t} \right)^{-\eta} y_t \left( \frac{P_t}{P_{it}} \right) = \eta \varphi \Psi_{it} h_{it+1} y_{it+1} \left( \frac{P_{it}}{P_{it-1}} - \pi \right) - Q_{t+1} \varphi \left( \frac{P_{it}}{P_{it-1}} - \pi \right) \left( \frac{P_{it+1}}{P_{it}} \right). \quad \text{(25)}$$

Since all intermediate firms face the same wage rate, face the same downward sloping demand curves, and have access to the same production technology, marginal costs, $mc_{it}$, are identical across all firms. Consequently, they hire the same amount of labor and produce the same amount of output. Therefore, we can restrict our attention to a symmetric equilibrium in which all firms make the same decisions. We thus drop all the subscripts $i$. That is, in equilibrium $y_{it} = y_t$, $P_{it} = p_t$, $mc_{it} = mc_t$, $\Psi_{it} = \Psi_t$, $n_{it} = n_t$, $h_{it} = h_t$. Consequently, equations (22), (23), and (25) can be simplified as:
\[ w_t = mc_t \alpha \frac{y_t}{n_t} \]  

(26)

\[ \Psi_t = E_t Q_{t+1} \pi_{t+1} \left[ mc_{t+1} \theta \frac{y_{t+1}}{h_{t+1}} + \Psi_{t+1} \left\{ (1 - \delta^h) + \gamma h_{t+1}^{\gamma - 1} y_{t+1}^\gamma \right\} \right] \]

(27)

\[ [1 - \eta + \eta mc_t] y_t = \varphi (\pi_t - \pi) \pi_t - \varphi E_t [q_{t+1} (\pi_{t+1} - \pi) \pi_{t+1}] + \Psi_t \eta h_t^\gamma y_t^\gamma, \]

(28)

where, \( \pi_t = \frac{\pi_t}{\pi_{t-1}} \), and \( q_t \) is the real discount factor.

Equation (26) is standard. When \( mc_t < 1 \), labor price \( w_t \) is less than the corresponding social marginal product \( \alpha \frac{n_t}{n_t} \). Equation (27) determines the optimal use of organizational capital by the firm. One additional unit of organizational capital has a (marginal) value, in terms of profits, of \( \Psi_t \) to the producer in the current period. The right hand side of (27) measures the value of having available an additional unit of organizational capital for use by the firm in the following period. First, the additional organizational capital directly contributes to the intermediate good production in the following period as captured by the first term on the right hand side. Second, the additional organizational capital today has a positive effect on the future stock of organizational capital which is captured by the two terms inside the curly bracket. First term inside the bracket is the un-depreciated additional stock and the second term is the new organizational capital stock generated by this additional stock. This higher stock of organizational capital has a value of \( \Psi_{t+1} \) to the producer. Finally, all of these next period values must be discounted by the factor \( Q_{t+1} \pi_{t+1} \). The condition (27) implies that organizational capital will be accumulated up to the point where the value of an additional unit of organizational capital today is equal to the discounted value of this organizational capital next period.

Finally, condition (28) represents the New Keynesian Phillips Curve which can be rearranged as,

\[
\left[ \frac{\eta - 1}{\eta} - mc_t \right] \eta y_t = -\varphi (\pi_t - \pi) \pi_t + \varphi E_t [q_{t+1} (\pi_{t+1} - \pi) \pi_{t+1}] \\
- q_{t+1} \left[ mc_{t+1} \theta \frac{y_{t+1}}{h_{t+1}} + \Psi_{t+1} \left\{ (1 - \delta^h) + \gamma h_{t+1}^{\gamma - 1} y_{t+1}^\gamma \right\} \right] \eta h_t^\gamma y_t^\gamma. \]

(29)

Price setting condition (29) describes an equilibrium relationship between the current deviation of marginal cost, \( mc_t \), from marginal revenue, \( (\eta - 1)/\eta \), current inflation, \( \pi_t \), expected future inflation, and expected change in future organizational capital. Under full price flexibility and without learning-by-doing effect in the technology, the firm would always set marginal revenue equal to marginal cost (there is no term on the right hand side of equation (29)). However, in the presence of either learning-by-doing effect in the production technology or the price adjustment costs, this practice is not optimal. Pricing decision in the current period has consequences for future costs and hence for profits. Therefore, firms set prices to equate an average of current and future expected marginal costs to an average of current and future expected marginal revenues.

Quadratic price adjustment costs impose some additional restrictions on firm’s price setting behavior which are captured by the first two terms on the right hand side of equation (29). By choosing a particular
price in period \( t \) the firm incurs a direct cost in the current period which is captured by the first term. In addition, this price change has consequences for the menu costs the firm will incur in period \( t + 1 \) which is reflected in the second term. Finally, the last term reflects the fact that the firm takes into account that its pricing decision today affects organizational capital tomorrow through the effect on demand and hence output. The expression \( \eta \varepsilon h^*_t y^*_t \left( = \frac{\partial h_{t+1}}{\partial y_{t+1}} \frac{\partial y_{t+1}}{\partial P_t} \right) \) represents the marginal change in organizational capital in period \( t + 1 \) due to a change in price in period \( t \). The expression \( q_{t+1}[..] \) represents the present value of a period \( t + 1 \) additional unit of organizational capital. For making a dynamically optimal decision the firm must consider this future costs incurred by the current pricing decision.

2.3. The Government

The government faces an exogenous, stochastic and unproductive stream of real expenditures denoted by \( g_t \). These expenditures are financed through labor income taxation, money creation, and issuance of one-period, risk-free, nominal debt. The government’s period-by-period budget constraint is then given by

\[
M_t + B_t + P_{t-1} \pi^n_{t-1} w_{t-1} n_{t-1} = M_{t-1} + R_{t-1} B_{t-1} + P_{t-1} g_{t-1}. \tag{30}
\]

As in Chari et al. (1991), government consumption is a credit good and thus \( g_{t-1} \) is not paid until period \( t \). The government does not have the ability to directly tax profits of the intermediate goods firms which is one of the reasons for the non-optimality of the Friedman Rule. Using the cash in advance constraint (3), we can eliminate the \( M \) terms and rewrite the government budget constraint as

\[
c_{1t} \pi_t + b_t \pi_t + \pi^n_{t-1} w_{t-1} n_{t-1} = c_{1t-1} + R_{t-1} b_{t-1} + g_{t-1}. \tag{31}
\]

where \( b_t = \frac{B_t}{P_t} \) denotes the real value of the nominal government debt in period \( t \).

2.4. Resource Constraint

Aggregating the time-\( t \) household budget constraint and the time-\( t \) government budget constraint yields the following resource constraint for the economy,

\[
c_{1t-1} + c_{2t-1} + g_{t-1} + \frac{\varphi}{2} (\pi_{t-1} - \pi) = y_{t-1}. \tag{32}
\]

The price adjustment cost appears in the resource constraint due to the fact that it represents an identical real resource cost incurred by the all intermediate goods firms. As discussed in Chugh (2006), the economy-wide resource frontier describes production possibilities for period \( t-1 \) because of the timing convention of the model – particularly, because all goods are paid for with a lag of one period, summing the time-\( t \) household and government budget constraints gives rise to the time \( t-1 \) resource constraint.

\footnote{In a non-Ramsey DSGE model, Johri (2009) discusses how LBD introduces a dynamic link between current production and future productivity and generates endogenous inertia in prices and output.}
2.5. Equilibrium

In the presence of government policy there are many competitive equilibria, indexed by different government policies. This multiplicity motivates the Ramsey problem\(^\text{11}\). In our model competitive and Ramsey equilibria are defined as follows:

2.5.1. Competitive Equilibrium

A competitive monetary equilibrium is a set of endogenous plans \(\{c_{1t}, c_{2t}, n_t, h_{t+1}, M_t, B_t, mct, \Psi_t, \pi_t\}\), such that the household maximizes utility taking as given prices and policies; the firms maximizes profit taking as given the wage rate, and the demand function; the labor market clears, the bond market clears, the money-market clears, the government budget constraint and the aggregate resource constraint are satisfied. In other words, all the processes above satisfy conditions (10), (14), (19), (26)-(28), (39)-(32) given policies \(\{\tau^n_t, R_t\}\), and the exogenous processes \(\{z_t, g_t\}\).

2.5.2. The Ramsey Equilibrium

The Ramsey equilibrium is the unique competitive equilibrium that maximizes the household’s expected lifetime utility. And the optimal fiscal and monetary policy is the process \(\{R_t, \tau^n_t\}\) associated with this Ramsey equilibrium. Following Schmitt-Grohé and Uribe (2006), we assume that the benevolent Ramsey Government has been operating for an infinite number of periods and it honors the commitments made in the past. This form of policy commitment is known as ‘optimal from the timeless perspective’ (see Woodford (2003)). Under this concept of Ramsey equilibrium, the structure of the optimality conditions associated with the equilibrium is time invariant. Formally, we can define the Ramsey Equilibrium as a set of stationary processes \(\{c_{1t}, c_{2t}, n_t, h_{t+1}, M_t, B_t, mct, \Psi_t, \pi_t, \tau^n_t, R_t\}\) that maximize:

\[E_0\sum_{t=0}^{\infty} \beta^t U(c_{1t}, c_{2t}, n_t)\]

subject to the resource constraint

\[c_{1t} + c_{2t} + g_t + \frac{\varphi}{2}(\pi_t - \pi)^2 - z_t n_t^\alpha h_t^\theta = 0, \quad (33)\]

the household’s first-order condition on bond accumulation

\[1 - R_t E_t \left[ \frac{\beta u_{1t+1}}{u_{1t}} \frac{1}{\pi_{t+1}} \right] = 0, \quad (34)\]

the optimal consumption-leisure condition

\[\frac{u_{3t}}{u_{2t}} - (1 - \tau^n_t)mc_t \frac{y_t}{n_t} = 0, \quad (35)\]

the organizational capital accumulation technology

\[h_{t+1} - (1 - \delta^h) h_t + h_t^\gamma y_t^\xi = 0, \quad (36)\]

\(^{11}\)The Ramsey theory have originated from the neoclassical, welfare-economic tradition of Ramsey (1927).
the intermediate firms first-order condition on organizational capital accumulation

\[ \Psi_t = E_t Q_{t+1} \pi_{t+1} \left[ mc_{t+1} \frac{y_{t+1}}{h_{t+1}} + \Psi_{t+1} \left\{ \left( 1 - \delta^h \right) + \gamma h_{t+1}^{\gamma-1} y_{t+1}^{\epsilon} \right\} \right] \]  

(37)

the New Keynesian Phillips Curve

\[ [1 - \eta + \eta mc_t] y_t = \varphi (\pi_t - \pi) \pi_t - \varphi E_t [q_{t+1} (\pi_{t+1} - \pi) \pi_{t+1}] + \Psi_t \eta h_t \gamma y_t^{\epsilon} , \]  

(38)

and the time \( t + 1 \) government budget constraint

\[ c_{1t+1} \pi_{t+1} + b_{t+1} \pi_{t+1} + \tau^n c_t \alpha \frac{y_t}{n_t} - c_t - R_t b_t - g_t = 0, \]  

(39)

given exogenous process \( g_t \), and \( z_t \), values of all the variables dated \( t < 0 \), the values of the Lagrange multipliers associated with the constraints listed above dated \( t < 0 \).

3. Parameterization and Functional Forms

The time unit in our model is one quarter. We set \( \beta = .9902 \) so that the discount rate is 4 percent (Prescott, 1986) per year. We follow Chugh (2007) in choosing the utility function and assume that the period utility function takes the following specification

\[ \ln c_t - \frac{\zeta}{1 + \mu} n_t^{1+\mu}. \]  

(40)

where,

\[ c_t = \left[ (1 - \sigma) c_{1t}^\sigma + \sigma c_{2t}^\sigma \right]^{\frac{1}{\sigma}} \]  

(41)

Chugh (2007) use the parameter values for \( \sigma \) and \( \nu \) from Siu (2004) where they were estimated by using the household optimality condition (10). We also use the same estimates \( \sigma = 0.62 \) and \( \nu = 0.79 \) as our base line. The parameter \( \mu \) governs disutility of work. We choose \( \mu = 1.7 \) which is consistent with Hall (1997) estimates of the elasticity of marginal disutility of work. The preference parameter \( \zeta \) was calibrated so that in the steady-state of the model without learning-by-doing and without nominal rigidities the consumer spends about one-third of his time working. We hold the corresponding value of \( \zeta \) (9.73) constant in all the environments considered in the paper. We choose \( \theta = 0.15, \gamma = 0.6, \) and \( \varepsilon = 0.4 \) in line with Cooper and Johri (2002). We set \( \delta^h = .1 \) which is equivalent to a yearly depreciation rate of 40%. This value is in line with Benkard (2000) estimate which suggests that the stock of experience depreciates by 39% yearly.

The exogenous processes for government spending, \( g_t \), and productivity, \( z_t \), are assumed to follow independent AR(1) in their logarithms,

\[ \ln (g_t / \bar{g}) = \rho_g \ln (g_{t-1} / \bar{g}) + \epsilon_t^g \]  

\[ \ln z_t = \rho_z \ln z_{t-1} + \epsilon_t^z \]  

13
with $\epsilon_t \sim iidN(0, \sigma_z^2)$ and $\epsilon_t^g \sim iidN(0, \sigma_g^2)$. $\bar{g}$ is the steady-state level of government spending and we calibrate this value so that government spending constitutes 17 percent of steady-state output. We choose the first-order autocorrelation parameters $\rho_z = 0.95$ and $\rho_g = 0.97$, the standard deviation parameters $\sigma_z = 0.007$ and $\sigma_g = 0.02$ in line with Chugh (2007) and the RBC literature. Following Schmitt-Grohé and Uribe (2006) we set i) the degree of imperfect competition parameter $\eta = 6$, and ii) the initial liabilities to government $B_1/P_0$ so that in the nonstochastic steady-state the government debt-to-GDP ratio is 44 percent per year. Finally, in line with Chugh (2006)\(^{12}\) we set the price-rigidity parameter $\varphi = 5.88$ which implies an average price stickiness of three quarters. Table-1 presents the baseline values of the structural parameters we use to obtain our main results.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.9902</td>
<td>subjective discount rate</td>
</tr>
<tr>
<td>$\eta$</td>
<td>6</td>
<td>price elasticity of demand</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>0.62</td>
<td>credit good share parameter in consumption</td>
</tr>
<tr>
<td>$\nu$</td>
<td>0.79</td>
<td>elasticity parameter in consumption</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>calibrated preference parameter</td>
<td></td>
</tr>
<tr>
<td>$\mu$</td>
<td>1.7</td>
<td>parameter governing disutility of work</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.85</td>
<td>share of labor in the production technology</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.15</td>
<td>share of organizational capital in production technology</td>
</tr>
<tr>
<td>$\delta_h$</td>
<td>0.1</td>
<td>depreciation rate of organizational capital</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.4</td>
<td>OC accumulation parameter, $h_{t+1} = (1 - \delta^h)h_t + h_t^\gamma h_t^\epsilon$</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.6</td>
<td>OC accumulation parameter</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>5.88</td>
<td>price adjustment cost parameter</td>
</tr>
<tr>
<td>$\bar{g}$</td>
<td>calibrated steady-state level of govt. spending</td>
<td></td>
</tr>
<tr>
<td>$\rho_g$</td>
<td>0.97</td>
<td>persistence in log govt. spending</td>
</tr>
<tr>
<td>$\sigma_g^z$</td>
<td>0.02</td>
<td>standard deviation of log govt. spending</td>
</tr>
<tr>
<td>$\rho_z$</td>
<td>0.95</td>
<td>persistence in log productivity</td>
</tr>
<tr>
<td>$\sigma_z^z$</td>
<td>0.007</td>
<td>standard deviation of log productivity</td>
</tr>
</tbody>
</table>

4. Quantitative Results

We characterize and solve the Ramsey equilibrium numerically using the methodology outlined in Schmitt-Grohé and Uribe (2006, 2007). They develop a set of numerical tools that allow the computation of

Ramsey policy in a general class of dynamic stochastic general equilibrium models. We first describe the optimal policy in the Ramsey steady-state and then present the simulation based dynamic results.

4.1. Ramsey Steady-States

To characterize the long-run state of the Ramsey equilibrium, first we derive the dynamic first-order conditions of the Ramsey problem. Then we impose the steady state and numerically solve the resulting non-linear system. This gives rise to the exact numerical solution of the long-run Ramsey problem.

Table 2 presents the Ramsey steady-state values of inflation, the nominal interest rate, and labor income tax rate under four different environments of interests. All the environments we consider are characterized by imperfectly competitive product market and hence the Friedman rule ceases to be optimal. Optimal interest rates are positive in all four cases because of the presence of monopoly profits. As explained in Schmitt-Grohé and Uribe (2004a), monopoly profits represent pure rents for the owners of the monopoly power, which the Ramsey planner would like to tax at 100 percent rate because it would be non-distortionary. If profit taxes are unavailable, which is the case in our environments, or restricted to be less then 100%, the Ramsey planner uses inflation/nominal interest rate as an indirect tax on profits. Thus, the Friedman rule of a zero net nominal interest rate is no longer optimal.

The presence of learning-by-doing (LBD) mechanism reduces the optimal rate of inflation and nominal interest rate in both flexible and sticky price environments. This finding is consistent with Schmitt-Grohé and Uribe (2004a), and Chugh (2006) finding that steady-state nominal interest rate/inflation increases with market power. For a given price elasticity of demand intermediate firms’ markup and hence market power falls due to the presence of learning-by-doing. This can be easily seen by rearranging the steady-state version of the New Keynesian Phillips Curve (29),

\[ mc = \frac{\eta - 1}{\eta} + \Psi \varepsilon h^\gamma y^{\gamma - 1}. \]  

(42)

\[ 13 \] In the steady state inflation and nominal interest rate has a direct relationship through the Fisher relation (10): \( \pi = \beta R. \)
In a standard Ramsey model with an imperfectly competitive product market, the real marginal cost $mc = \frac{\eta - 1}{\eta}$. However, in our model $mc$ increases from $\frac{\eta - 1}{\eta}$ toward 1 because of the presence of learning-by-doing effect (the second term on the right hand side of equation (42)). The higher the $mc$, the lower the markup\(^{14}\) and hence monopoly profit. Thus, the steady state net nominal interest rate and inflation are lower than the rate suggested by a otherwise similar model without learning-by-doing. Finally, the labor income tax rate is also falling with learning-by-doing which is consistent with Schmitt-Grohé and Uribe (2004a). The labor tax base shrinks with monopoly power because the higher the monopoly power, the higher the wedge between wages and marginal product of labor. And a lower tax base calls for a higher labor income tax rate. In our model, learning-by-doing decreases the market power, increases the labor tax base and hence calls for a lower rate of the labor income tax.

We can also analyze how the steady-state policy responds to different values of learning parameters. Table 3 displays the steady-state Ramsey policy for different values of $\varepsilon$, $\gamma$, and $\delta^h$. In this exercise while we change the value of one of the parameters we keep the other parameters constant at their baseline values. As the table shows, nominal interest rate, and consequently inflation rates, decline as either $\varepsilon$ or $\gamma$ rises and $\delta^h$ falls. Again, the intuition draws from equation (42). A higher value for either $\varepsilon$ or $\gamma$ or a lower value for $\delta^h$ (\(=\) higher value of $\Psi$) imply higher rate of learning and a higher value for $mc$ (the table clearly shows these expected changes in the value of $mc$). And a higher value of $mc$ implies a lower markup and hence lower monopoly profit. Finally, the labor income tax rates falls as $\varepsilon$ or $\gamma$ increases or

<table>
<thead>
<tr>
<th>$\varepsilon$</th>
<th>$\pi - 1$</th>
<th>$R - 1$</th>
<th>$\tau^n$</th>
<th>$mc$</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>-0.4464</td>
<td>3.5357</td>
<td>0.23667</td>
<td>0.9314</td>
<td>0.3658</td>
</tr>
<tr>
<td>0.40</td>
<td>-2.1315</td>
<td>1.7832</td>
<td>0.23282</td>
<td>0.9473</td>
<td>0.3688</td>
</tr>
<tr>
<td>0.45</td>
<td>-3.0239</td>
<td>0.85511</td>
<td>0.22892</td>
<td>0.9638</td>
<td>0.3719</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$\pi - 1$</td>
<td>$R - 1$</td>
<td>$\tau^n$</td>
<td>$mc$</td>
<td>$n$</td>
</tr>
<tr>
<td>0.55</td>
<td>-0.3437</td>
<td>3.6425</td>
<td>0.2339</td>
<td>0.9420</td>
<td>0.3678</td>
</tr>
<tr>
<td>0.60</td>
<td>-2.1315</td>
<td>1.7832</td>
<td>0.23282</td>
<td>0.9473</td>
<td>0.3688</td>
</tr>
<tr>
<td>0.65</td>
<td>-3.7673</td>
<td>0.081981</td>
<td>0.22942</td>
<td>0.9620</td>
<td>0.3715</td>
</tr>
<tr>
<td>$\delta^h$</td>
<td>$\pi - 1$</td>
<td>$R - 1$</td>
<td>$\tau^n$</td>
<td>$mc$</td>
<td>$n$</td>
</tr>
<tr>
<td>0.11</td>
<td>-0.7351</td>
<td>3.2355</td>
<td>0.23359</td>
<td>0.9446</td>
<td>0.3683</td>
</tr>
<tr>
<td>0.10</td>
<td>-2.1315</td>
<td>1.7832</td>
<td>0.23282</td>
<td>0.9473</td>
<td>0.3688</td>
</tr>
<tr>
<td>0.09</td>
<td>-3.0847</td>
<td>0.79189</td>
<td>0.23213</td>
<td>0.9497</td>
<td>0.3692</td>
</tr>
</tbody>
</table>

Note: The net inflation rate, $\pi - 1$, and the net nominal interest rate, $R - 1$, are expressed in percent per year.

\(^{14}\)Note that $mc$ is the real marginal cost in our model and hence $\frac{1}{mc}$ represents the gross markup.
δ\textsuperscript{h} falls. As the last column of the table confirms, this result is due to an increasing labor tax base.

4.2. Ramsey Dynamics

We compute the numerical solution to the Ramsey problem based on a second-order approximation of the Ramsey planner’s decision rules. We approximate the model in levels around the non-stochastic steady-state based on the perturbation algorithm described in Schmitt-Grohé and Uribe (2004a). As in Schmitt-Grohé and Uribe (2004c), we first generate simulated time series of length 100 for the variables of interest and then compute the first and second moments. We repeat the procedure 500 times and report the averages of the moments. Table 4 presents the simulation based moments for key real and policy variables generated from different model environments. As the table shows, the central result of the paper — stable and persistent inflation — is generated only when both learning-by-doing and price rigidity are introduced in the model. While learning-by-doing generates the persistence, price rigidity generates the stability in the Ramsey inflation.

The top panel of Table 4 displays results for the model without any price rigidities or learning-by-doing effects in the production technology. As in Schmitt-Grohé and Uribe (2004a), inflation is characterized by high volatility and low persistence in this environment. The reason is that the Ramsey planner uses surprise inflation as a lump-sum tax on households’ financial wealth. Inflation does not impose any real resource cost to the economy and hence it is optimal to use it in response to unanticipated changes in the state of the economy. By varying the price level in response to shocks the Ramsey planer actually makes the riskless nominal debt state-contingent in real terms. In this flexible price environment, debt serves as a shock absorber which allows the Ramsey planner to maintain very smooth paths for the distortionary labor income taxes and interest rates over the business cycle. This intuition is supported by the very low standard deviation and high persistence of the labor income tax \( \tau \).

The second panel of Table 4 shows results for the model with flexible prices and learning-by-doing effect in the production technology. As price is still fully flexible and inflation does not incur any resource costs, LBD itself can’t reduce the volatility of optimal inflation significantly. The main contribution of learning is the generation of substantial persistence in optimal inflation and in a few other variables. We can draw intuition for the higher inflation persistence from the New Keynesian Phillips curve (29). Without the price stickiness this pricing equation becomes:

\[
mc_t - \frac{\eta - 1}{\eta} = E_t q_{t+1} \left[ mc_{t+1} \theta \frac{y_{t+1}}{h_{t+1}} + \Psi_{t+1} \left\{ (1 - \delta^h) + \gamma h_{t+1}^{-1} y_{t+1} \right\} \right] \varepsilon_{h_t} \gamma_{t} y_t^{-1} \tag{43}
\]

Although the quadratic price adjustment costs are absent in this environment the presence of LBD makes the pricing decision of the firm dynamic. Intermediate firms realize that a current price change affects organizational capital, productivity, cost, and hence profits in all future periods. Therefore, they no longer follow a static pricing rule of equating time \( t \) marginal cost, \( mc_t \), and time \( t \) marginal revenue, \( \frac{\eta - 1}{\eta} \). For maximizing lifetime profits they now take into account the future effects (which is captured by the terms on the right hand side of equation (43)) on cost and profits of a current pricing decision. This
Table 4: Dynamic properties of Ramsey allocation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Auto. corr.</th>
<th>Corr(x,y)</th>
<th>Corr(x,g)</th>
<th>Corr(x,z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible prices without LBD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\tau^n)</td>
<td>0.2360</td>
<td>0.06169</td>
<td>0.8457</td>
<td>-0.3064</td>
<td>0.8728</td>
<td>-0.1332</td>
</tr>
<tr>
<td>(\pi^{-1})</td>
<td>-0.4335</td>
<td>3.5436</td>
<td>-0.0141</td>
<td>-0.1167</td>
<td>0.1455</td>
<td>-0.0933</td>
</tr>
<tr>
<td>(R^{-1})</td>
<td>3.5614</td>
<td>0.6243</td>
<td>0.1135</td>
<td>0.1043</td>
<td>0.0480</td>
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</tr>
<tr>
<td>(y)</td>
<td>0.3351</td>
<td>0.0052</td>
<td>0.9014</td>
<td>1.0000</td>
<td>-0.1030</td>
<td>0.9692</td>
</tr>
<tr>
<td>(n)</td>
<td>0.3352</td>
<td>0.0012</td>
<td>0.3277</td>
<td>0.2179</td>
<td>-0.4278</td>
<td>-0.0147</td>
</tr>
<tr>
<td>(c)</td>
<td>0.2763</td>
<td>0.0040</td>
<td>0.9430</td>
<td>0.7935</td>
<td>-0.6456</td>
<td>0.7114</td>
</tr>
<tr>
<td>Flexible prices with LBD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\tau^n)</td>
<td>0.2335</td>
<td>0.3649</td>
<td>0.8709</td>
<td>0.6642</td>
<td>0.6140</td>
<td>0.2729</td>
</tr>
<tr>
<td>(\pi^{-1})</td>
<td>-1.4248</td>
<td>2.8240</td>
<td>0.6626</td>
<td>-0.4391</td>
<td>0.4963</td>
<td>-0.2411</td>
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<tr>
<td>(R^{-1})</td>
<td>2.5143</td>
<td>0.8588</td>
<td>0.9114</td>
<td>-0.5297</td>
<td>0.7652</td>
<td>-0.5790</td>
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<tr>
<td>(y)</td>
<td>0.11573</td>
<td>0.0163</td>
<td>0.8995</td>
<td>1.0000</td>
<td>0.0487</td>
<td>0.9957</td>
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<tr>
<td>(n)</td>
<td>0.3467</td>
<td>0.0005</td>
<td>0.8931</td>
<td>-0.4102</td>
<td>0.8600</td>
<td>-0.4665</td>
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<tr>
<td>(c)</td>
<td>0.9449</td>
<td>0.0094</td>
<td>0.9010</td>
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<td>-0.1400</td>
<td>0.9877</td>
</tr>
<tr>
<td>Sticky prices without LBD</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(\tau^n)</td>
<td>0.2389</td>
<td>1.1572</td>
<td>0.8232</td>
<td>-0.2360</td>
<td>0.9559</td>
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<td>(\pi^{-1})</td>
<td>-0.6108</td>
<td>0.0400</td>
<td>0.0337</td>
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<td>(R^{-1})</td>
<td>3.2409</td>
<td>0.8531</td>
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<tr>
<td>(y)</td>
<td>0.3819</td>
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<td>0.9977</td>
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<tr>
<td>(n)</td>
<td>0.3320</td>
<td>0.0004</td>
<td>0.9319</td>
<td>0.0514</td>
<td>-0.7189</td>
<td>-0.0044</td>
</tr>
<tr>
<td>(c)</td>
<td>0.2872</td>
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<td>0.9054</td>
<td>0.8743</td>
<td>-0.4868</td>
<td>0.8515</td>
</tr>
<tr>
<td>Sticky prices with LBD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\tau^n)</td>
<td>0.2323</td>
<td>0.3292</td>
<td>0.9497</td>
<td>0.5851</td>
<td>0.6373</td>
<td>0.4592</td>
</tr>
<tr>
<td>(\pi^{-1})</td>
<td>-2.1234</td>
<td>0.0397</td>
<td>0.9059</td>
<td>-0.2282</td>
<td>0.7621</td>
<td>-0.4452</td>
</tr>
<tr>
<td>(R^{-1})</td>
<td>1.7974</td>
<td>0.1514</td>
<td>0.9171</td>
<td>-0.0871</td>
<td>-0.8523</td>
<td>0.1260</td>
</tr>
<tr>
<td>(y)</td>
<td>1.0189</td>
<td>0.0158</td>
<td>0.8991</td>
<td>1.0000</td>
<td>0.2405</td>
<td>0.9552</td>
</tr>
<tr>
<td>(n)</td>
<td>0.3690</td>
<td>0.0021</td>
<td>0.9113</td>
<td>-0.2725</td>
<td>0.8121</td>
<td>-0.5139</td>
</tr>
<tr>
<td>(c)</td>
<td>0.8449</td>
<td>0.0093</td>
<td>0.9024</td>
<td>0.8087</td>
<td>-0.3167</td>
<td>0.9373</td>
</tr>
</tbody>
</table>

Note: The net inflation rate, \(\pi^{-1}\), and the net nominal interest rate, \(R^{-1}\), are expressed in percent per year.

dynamic feature on the part of firms’ price setting behavior significantly influences inflation persistence. More intuitively, suppose there is a deflation (due to a price reduction) this period. Given that firms face a downward sloping demand curve for their products, they now have to increase output to meet the additional demand. More output production this period causes larger accumulation of production knowledge which lowers the future costs. As the firms face relatively lower marginal costs in the next period, they optimally set a relatively lower price (which causes further deflation) in the next period as
well. By similar arguments, higher prices (inflation) this period will induce firms to set relatively higher prices in the next period as well. That is why optimal inflation is very persistent in the environments with LBD mechanism in the production technology.

The third panel of Table 4 presents results for the model with sticky prices but without any learning-by-doing effect in the production technology. This model is comparable to other standard sticky price Ramsey models - e.g. Schmitt-Grohé and Uribe (2004b) and Siu (2004). In line with their findings, the volatility of optimal inflation decreases substantially as compared to the baseline model of the top panel - the standard deviation of inflation falls from over three to near zero - but the autocorrelation coefficient still has a value near zero. The reason for this inflation stability is that when price adjustment is costly, the Ramsey planner balances the shock absorbing benefits of state-contingent inflation against the associated resource misallocation costs. In particular, he/she keeps the price changes to a minimal level because the associated resource misallocation costs largely dominate the value of state-contingent lump-sum levies on nominal wealth.

The bottom panel of Table 4 shows results for the model with both sticky prices and learning-by-doing effect. Optimal inflation is now characterized by very low volatility and very high persistence - exactly opposite to the inflation dynamics found in the baseline model of the top panel. After going through the results of different models it is now somewhat clear that while learning-by-doing generates the high persistence, the price rigidities generates the low volatility in optimal inflation. The magnitude of inflation volatility is almost unchanged between the model of panel 3 (sticky prices without LBD) and the full model of the bottom panel (sticky prices with LBD). However, the inflation persistence increased significantly in the full model (Sticky prices with LBD) as compared to the model of panel 3 (sticky prices without LBD). As equation (27) indicates, a very stable path of optimal inflation implies a more stable path for the value of organizational capital, $\Psi_t$. This extra stability in the value of organizational capital has contributed to the persistence of optimal inflation through the New Keynesian Phillips curve (29). Another way to think about this feature is that in a model with both LBD and price stickiness, the inflation directly depends on past, present, and future values of a number of variables through the New Keynesian Philips Curve. More specifically with LBD, inflation $\pi_t$ depends on $h_{t-1}$, $y_{t-1}$, $h_t$, $y_t$, $mc_t$, $h_{t+1}$, $y_{t+1}$, $mc_{t+1}$, $\Phi_{t+1}$, $\pi_{t+1}$ through (29). This generates some extra smoothness in the optimal inflation path.

Finally, as Table 4 clearly shows, optimal tax policy is pro-cyclical - tax rates fall during the boom and rise during recession - in the models without LBD. In a standard model environment, to finance an exogenous stream of spending the Ramsey planner increases the tax rates when output is relatively low. However, in presence of LBD mechanism in a model this practice is not optimal. Actually, the optimal tax policy becomes counter-cyclical. The basic intuition is that the planner does not want hours to fall when negative technology shock hits the economy. A higher labor income tax rate would lower hours, output and hence organizational capital which would magnify/propagate the shock further by lowering...
future productivity. Therefore, to mitigate the effects of a negative technology shock, the planner would optimally lower the tax in order to raise the after tax return to work. In other words, the planner leans against the wind. How can the planner do this? He must be increasing the other tax(es) at the same time to pay for the reduction in labor tax revenues. This is indeed the case as the correlation of inflation with the technology shock becomes more strongly negative. Also, notice that average inflation and nominal interest rates fall in presence of LBD. Again, the reason for this is that learning-by-doing reduce markup and hence monopoly profits. Average labor tax rates falls in LBD models mostly due to the increase of the tax base.

5. Conclusion

This paper characterizes optimal fiscal and monetary policy with price rigidity and organizational learning-by-doing in the production technology. The economic environment considered features a government that finances an exogenous stochastic stream of spending by levying distortionary income taxes, printing money, and issuing nominal risk-free debts. Our central finding is that, the optimal inflation associated with the Ramsey allocation is very stable and persistent over the business cycle. The key for our results is some new features in the New Keynesian Philips Curve – the firms’ optimal price setting condition. Inflation is optimally persistent because there is a dynamic link between current production and future productivity. Monopolistic firms face a downward sloping demand curve for their products and a higher price has to be matched with a cut in production. Lower production affects firms learning and generation of organizational capital negatively which lowers productivity and increases costs in all future periods. Inflation is optimally stable because changes in inflation come at a resource cost. Another important result is that optimal tax policy is counter-cyclical in our model which contrasts with pro-cyclical tax results obtained in standard sticky price Ramsey models. Finally, the presence of organizational learning increases the competitiveness of the product market and hence reduces the nominal interest rates, inflation, and the labor income tax rates.

References


