Reset Price Inflation and Monetary Policy

Engin Kara

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Department of Economics
University of Bristol
8 Woodland Road
Bristol BS8 1TN

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Engin Kara†

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Abstract

Bils, Klenow and Malin (2009) recently constructed an empirical measure of reset price inflation (i.e. the rate of change of all "desired" prices) for the US economy, by using the micro-data underpinning the CPI and evaluated whether the existing pricing models can explain both the observed reset inflation and aggregate inflation. They found that time-dependent models and state-dependent models are both inadequate in this respect. This paper presents a model that tracks the data on reset inflation perfectly well. A main difference between the model in this paper and those in Bils et al. (2009) is that the model in this paper properly accounts for the heterogeneity in contract lengths we observe in the data.

Keywords: DSGE models, reset inflation.

JEL: E32, E52, E58.

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†University of Bristol, Economics Department, 8 Woodland Road, Bristol, BS8 1TN. E-mail: engin.kara@bristol.ac.uk.

1 Introduction

Recent work by Bils et al. (2009) (BKM) constructs an empirical index of reset prices between January 1989 and May 2008, using the micro data on prices collected by the US Bureau of Labour Statistics for the CPI. The dataset cover about 70% of the CPI. This is the same database as Klenow and Kryvtsov (2008) used, only updated by more recent years. To construct this measure, the authors, for each month, divide items into two categories: those that change price and those that do not. For those that change price, the reset price is simply the current price. For those that do not change price, the reset price is updated according to the rate of reset inflation among price changers in the current period. The updated prices are the reset prices for those that do not change price. The reset price in the economy is the weighted average of all reset prices. This inflation index is similar to the inflation index constructed by Shiller (1991) for house prices. This measure might be best understood with an example, which is similar to the example provided by the authors. Consider an economy with two goods, each with an equal share: A and B. Assume that Good A's price increases by 20% in period t, whereas Good B's price remains unchanged. The reset inflation for Good A in period t is simply 20%. Aggregate inflation in the economy is 10%. Now consider the case in which in period $t+1$ Good B's price increases by 20%, whereas Good A's price remain unchanged. The reset inflation for Good B is zero, since the increase in Good A's price in period t also increases the base price for calculating reset inflation for Good B by 20%. Thus, reset inflation for both Goods A and B in period $t + 1$ is zero, whereas aggregate inflation is again 10%.

This measure of inflation is important for evaluating how far existing models are consistent with the firm-level data. As shown by Levin, López-Salido, Nelson and Yun (2008) and Kara (2010), micro-evidence on firm behaviour can significantly affect policy conclusions.

BKM employ two-sectors models to examine whether they can track the data on reset inflation. They argue that neither time-dependent nor state dependent models can explain the observed reset inflation. They find that the both models generates high degree of persistence, compared with the data.

This paper evaluates whether a model that accounts for the heterogeneity in contract lengths can explain the persistence and nontrivial volatility of reset inflation. For this purpose, I employ a multiple Calvo Economy (MC). In this model, there are many sectors, each with a Calvo reset probability, as in Carvalho (2006). A main finding of the paper is that the MC based on the Klenow and Kryvtsov (2008) dataset can explain both the low persistence and nontrivial volatility of observed reset price inflation perfectly well.

A natural question is why BKM reach a different conclusion that time dependent models fail to explain the observed reset inflation dynamics. My modeling approach differs from that in BKM in that in BKM aggregate demand is given by the simple quantity theory, whereas in this paper aggregate demand is given by the Euler condition. They only allow for monetary policy shocks, whereas I allow for monetary policy shocks as well as productivity shocks. Moreover, they assume that monetary policy is conducted according to a money supply rule, whereas I assume that monetary policy is conducted according to a Taylor rule. However, as I will show later in the text, their conclusion is also true in my setting. The trouble in BKM's analysis arises because the authors attempt to approximate the US economy with a simple two-sector model. The two sector model employed by these authors has a distribution of contract lengths that is different from the distribution suggested by the data. The BKM distribution underestimates the share of flexible contacts compared to the Klenow and Kryvtsov (2008) distribution.

The remainder of the paper is organised as follows. Section 2 presents the model. Section 3 presents evidence on reset price inflation. Section 4 presents results. Section 5 concludes the paper.

2 The Model

The model is based on the *GTE* framework of Dixon and Kara (2010a). In this otherwise standard Dynamic Stochastic General Equilibrium (DSGE) model, there can be many sectors, each with a different contract length. When all the contracts have the same duration in the economy, the model reduces to a standard Taylor model. An advantage of the *GTE* approach is that it is general enough to represent any distribution of contract lengths, including those generated by the Calvo model. The Calvo model is different from the GTE because the wage setters do not know how long the contract will last: each period a fraction ω of firms/households chosen randomly start a new contract. However, the Calvo process can be described in deterministic terms at the *aggregate* level because the firm-level randomness washes out. As shown in Dixon and Kara (2006), the distribution of contract lengths across firms is given by $\alpha_i = \omega^2 i(1-\omega)^{i-1} : i = 1...\infty$, with mean contract length $T = 2\omega^{-1} - 1$. The GTE also has a multiple Calvo model as a special case. The model here differs from the one in Dixon and Kara (2010a), which assumes that wages are sticky whereas goods prices are flexible. Herein I assume that wages are flexible whereas goods prices are sticky.

2.1 Structure of the Economy

As in a standard DSGE model, in the model economy, there is a continuum of firms $f \in [0,1]$. Corresponding to the continuum of firms f, there is a unit interval of household-unions ($h \in [0,1]$). Each firm is then matched with a firm-specific union($f = h$) [1]. The unit interval is divided into N sectors, indexed by $i = 1...N$. The share of each sector is given by α_i witjh $\sum_{i=1}^{N} \alpha_i = 1$. Within each sector i, there is a Taylor process. Thus, there are i equally sized cohorts $j = 1...i$ of unions and firms. Each cohort sets the price which lasts for T_i periods: one cohort moves each period. The share of each cohort

[1] This assumption means that there is a firm- specific labour market. The implications of this assumption for inflation dynamics are well known (see, for example, Dixon and Kara (2007) and Edge (2002), Woodford (2003)).

j within the sector i is given by $\lambda_{ij} = \frac{1}{T_i}$ where $\sum_{j=1}^{T_i} \lambda_{ij} = 1$. The longest contracts in the economy are N periods.

A typical firm produces a single differentiated good and operates a technology that transforms labour into output subject to productivity shocks in that sector. The final consumption good is a constant elasticity of substitution (CES) aggregate over the differentiated intermediate goods. Given the assumption of CES technology, the demand for a firm's output $(y_{tf}\ )$ depends on the general of price(p_t), its own price (p_{ft}) and the output level (y_{ft}) : $y_{it} = \theta(p_t - p_{ft}) + y_t$, where θ measures the elasticity of substitution between goods. Thus, the only commonalities within a sector are that all firms in the same sector have the same contract length and are hit by the same shocks. The other elements of the model are standard New Keynesian. The representative household derives utility from consumption and leisure. The government conducts monetary policy according to a Taylor rule.

2.2 Log-linearized Economy

In this section, I will simply present the log-linearized macroeconomic framework.[2] Before defining the optimal price setting rule in the GTE, it is useful to define the optimal price that would occur if price were perfectly flexible $(\bar{p}_{it})$ (i.e. "the optimal flex price"). The log-linearized version of the optimal

[2] A technical appendix at the end of the paper provide a detailed discussion of the underlying assumptions of the model and the derivation of the structural equations.

flex price in each sector is given by

$$\bar{p}_{it} = p_t + \gamma y_t - \delta a_t \tag{1}$$

with the coefficients γ and δ being:

$$\gamma = \frac{\eta_{cc} + \eta_{_{LL}}}{1 + \theta \eta_{_{LL}}} \text{ and } \delta = \frac{1 + \eta_{_{LL}}}{1 + \theta \eta_{_{LL}}} \tag{2}$$

Where $\eta_{cc} = \frac{-U_{cc}C}{U_c}$ is the parameter governing risk aversion, $\eta_{_{LL}} = \frac{-V_{LL}H}{V_L}$ is the inverse of the labor elasticity and θ is the sectoral elasticity. a_t denotes productivity shocks, which follows an $AR(1)$ process: $a_t = \rho a_{t-1} + \varepsilon_t$, where ε_t is an $idd(0, \sigma_a^2)$. The optimal flex prices will, in general, differ across sectors, since the sectors are hit by different shocks.

We can represent the price-setting behaviour in the GTE in terms of three general equations: one for the optimal price in sector i (x_{it}), one for the average price in sector i (p_{it}) and one for the average price in the economy (p_{it}). These are:

$$x_{it} = \sum_{j=1}^{T_i} \lambda_{ij} \bar{p}_{it+j-1} \tag{3}$$

$$p_{it} = \sum_{j=1}^{T_i} \lambda_{ij} x_{it-(j-1)} \tag{4}$$

$$p_t = \sum_{i=1}^{N} \alpha_i p_{it} \tag{5}$$

where $\lambda_{ij} = \frac{1}{i}$. The optimal price (3) in sector i is simply the average (expected) optimal flex price over the contract length (the nominal price is constant over the contract length). The optimal prices will, in general, differ across sectors, since they take the average over a different time horizon and are hit by different shocks. The average price in sector i (4) is related to the past optimal prices in that sector. The average price in the economy (5) is simply the weighted average of all ongoing sectoral prices.

These equations (3 - 5) can represent the multiple Calvo economy, in which there are many sectors, each with a Calvo-style contract. To obtain the simple Calvo economy from (3), the summation is made with $T_i = \infty$ and $\lambda_{ij} = \omega_i(1-\omega_i)^{j-1} : j = 1...\infty$, where ω_i is the Calvo hazard rate for sector i.

The output level in the economy is given by the standard Euler condition:

$$y_t = E_t y_{t+1} - \eta_{cc}^{-1}(r_t - E_t \pi_{t+1}) \tag{6}$$

where $\pi_t = p_t - p_{t-1}$ is the inflation rate and r_t is the nominal interest rate.

Following Taylor and Wieland (2008), the central bank follows a Taylor style rule under which the short term interest rate is adjusted to respond to the inflation rate and the current and lagged output levels:

$$r_t = \phi_\pi \pi_t + \phi_y(y_t - y_{t-1}) + \xi_t \tag{7}$$

where ξ_t is a monetary policy shock and follows a white noise process with zero mean and a finite variance.

The average reset inflation for price changers at period t is given by

$$\tilde{\pi}_t = \sum_{i=1}^{N} \alpha_i \lambda_{ij} \left(x_{it} - x_{it-1}\right) \tag{8}$$

When constructing their empirical measure of reset inflation, BKM assume that firms that do not change price in the current period update their prices according to the average inflation for price changers ($\tilde{\pi}_t$). Thus, the reset price in sector i is given by

$$p_{it}^* = \sum_{j=1}^{T_i} \lambda_{ij} \left(x_{it-(j-1)} + \sum_{k=0}^{j-2} \tilde{\pi}_{t-k} \right) \tag{9}$$

If we define aggregate reset inflation as $\pi_t^* = p_t^* - p_{t-1}^*$, we have:

$$\pi_t^* = \sum_{i=1}^{N} \alpha_i \pi_{it}^* \tag{10}$$

where $\pi_{it}^* = p_{it}^* - p_{it-1}^*$ is the sectoral reset inflation.

2.3 Choice of Parameters

The time period of calibration is monthly. I use the KK dataset to calibrate a MC. The data are derived from the US Consumer Price Index data collected by the *Bureau of Labor Statistics*. The period covered is 1988-2005, and about 300 categories account for about 70% of the CPI. The dataset provides the average proportion of prices changing per month for each category. I interpret these statistics as Calvo reset probabilities and use them to calibrate a MC. Following the literature, (e.g. Walsh (2005), Woodford (2003)), I set $\eta_{LL} = 1.2$,and $\eta_{CC} = 1$. Midrigan (2005) uses $\theta = 3$. Golosov and Lucas (2007) and Chari, Kehoe and McGrattan (2000) use higher values of θ. Golosov and Lucas (2007) use $\theta = 7$, while Chari et al. (2000) use $\theta = 10$. Given these numbers, I set $\theta = 4$. I set $\rho = 0.45$ and $\sigma_a = 4.95\%$, in line with BKM[3] I set $\phi_\pi = 1.1$ and $\phi_y = 0.5$, in line with Taylor (1999). Following BKM, I set the standard deviation of monetary policy shocks to 0.48%.

3 Evidence on Reset Price Inflation

Table 1 reports summary statistics on BKM's empirical measure of reset inflation as well aggregate inflation. The first row of Table 1 reports the persistence of reset inflation. The persistence of these series is measured by the first-order autocorrelation. As the table shows, there is no persistence in reset inflation. The serial correlation is negative at around -0.47. Another feature is that reset inflation is less persistent than aggregate inflation. The third row of Table 1 reports the persistence of reset inflation. The serial correlation of aggregate inflation is around -0.12. The table further indicates that aggregate inflation is less volatile than reset inflation. The standard deviation of reset inflation is around 0.99%, whereas the standard deviation

[3] BKM calibrate the standard deviations of idiosyncratic productivity shocks in their menu cost model at around 5%.

of aggregate inflation is around one-fifth of that of reset inflation.

	All goods
Standard deviation of π^*	0.99%
Serial correlation of π^*	-0.47
Standard deviation of π	0.18%
Serial correlation of π	-0.12

Table 1: Summary Statistics for monthly Reset and Aggregate Price Inflation (source: BKM)

Note that, in addition to aggregate statistics, BKM also report statistics for two subgroups: flexible goods and sticky goods. However, this categorization can be misleading, since the flexible goods group does not consist only of goods that adjust their prices every period. BKM report that the mean frequency of price changes in this group is 0.33. If within each group there is a Calvo process, then in the flexible group there are plenty of contracts longer than 1-period. The mean frequency in the sticky good group is 10%. The statistics reported by BKM for two groups are similar. This is not surprising because the groups have similar frequencies of price changes. Therefore, these statistics have limited value. Thus, I do not report these statistics here.

4 Results

Having reviewed the stylised features we can ask the following question: can a DSGE model that accounts for the heterogeneity in contracts lengths explain these features? Table 3 provides an answer to this question. There, I report summary statics for the MC based on the Klenow and Kryvtsov (2008) dataset (hereafter, KK-MC) [4][5].

As the table shows, the standard deviation and serial correlation of reset inflation match the empirical statistics. The model also closely aligns with aggregate inflation data. The persistence of aggregate inflation in the model is exactly the same as in the data. Moreover, as in the data, aggregate inflation is less volatile than reset inflation. The reason for this result is simple: aggregate inflation includes many prices that are fixed. The only feature that the model is unable to explain as perfectly as the other features is the volatility of aggregate inflation. Aggregate inflation in the model is more volatile than what the data suggests. The standard deviation of aggregate inflation in the model is 0.49%, whereas it is 0.18% in the data.

	All goods
Standard deviation of π^*	0.99%
Serial correlation of π^*	-0.47
Standard deviation of π	0.49%
Serial correlation of π	-0.12

Table 2: Summary Statistics for bi-monthly Reset and Aggregate Price Inflation

These results suggest that the model does a remarkable job of accounting

[4]The series are HP-filtered, as in the data. However, the results are not affected by HP filtering, beacuse the HP-filter employed is smooth, with a penalty parameter of one million.

[5]All calculations are performed using Dynare version 4.1 (see Juillard (1996)).

for the observed persistence and volatility of both reset inflation and aggregate inflation. This is true even though the model exhibits strategic complementarity among firms. BKM argue that strategic complementarities push models away from the data moments. In the model, γ is a measure of the degree of strategic complementarity of firm pricing decisions. If $\gamma < 1$, then the model exhibits strategic complementarities. If $\gamma > 1$, then in the model firm decisions are strategic substitutes. My calibrated parameter value, $\gamma = 0.38$, implies a large degree of strategic complementarity.

So, why do BKM argue that time-dependent models cannot fit the empirical estimates reported in Table 1? To understand the differences between our conclusions, first note that BKM divide their sample into two groups. As noted above, in one of the groups, which they label the flexible sector, the monthly mean frequency is 0.33 and in the other one, which is labeled the sticky sector, it is 0.10. The share of the flexible group is 30%, whereas the share of the sticky group is 70%. They interpret these frequencies as the Calvo hazard rates. They then used these numbers to calibrate a two-sector Calvo economy. They find that reset inflation in this model is more persistent and less volatile than the data. To understand why this is the case, I derive the distribution of contract lengths across firms in the model employed by BKM and compare it with the distribution of contract lengths across firms from the Klenow and Kryvtsov (2008) dataset. To derive these distributions, I use the formula put forward by Dixon and Kara (2006). Under the assumption that within each sector there is a Calvo-style contract, the distributions in terms of months are plotted in Figure 1. Interestingly enough, the two distributions have the same mean (i.e. 14 months). However, as the figure shows, the distribution in the BKM economy is different from the distribution that the KK dataset suggests. More specially, the BKM distribution significantly underestimates the share of the flexible contracts compared with the "true" share. The share of 1 and 2 period contracts in the BKM distribution is around 5%, whereas in the KK distribution it is around 25%.

One would suspect that given the higher share of longer contracts in the BKM distribution, in the BKM economy prices would adjust more sluggishly than the KK-MC. Table 3 confirms this suggestion. There, I report the summary statistics of reset inflation and aggregate inflation for BKM's Calvo economy. All the parameters are calibrated as in the KK-MC. The persistence of reset inflation in the BKM model is the almost the same as that in the data. The serial correlation of reset inflation in the model is -0.44, whereas it is -0.47 in the data. However, given the higher share of longer-term contacts in the BKM, aggregate inflation is considerably more persistent more persistent in the BKM than in the MC. The serial correlation of aggregate inflation in the model is -0.12, whereas it is 0.28 in the data. Related to this result, reset inflation is considerably less volatile than in the data. The standard deviations of reset inflation is about one-fourth of what it is in the data.

	All goods
Standard deviation of π^*	0.27%
Serial correlation of π^*	-0.44
Standard deviation of π	0.14%
Serial correlation of π	0.28

Table 3: Summary Statistics for monthly Reset and Aggregate Price Inflation from BKM's 2-sector Calvo Model

Thus, these results clearly show that the BKM conlusion that time-dependent models cannot account for the observed reset inflation dynamics arises due their simplifying assumption that the US economy can be represented by a two sector model[6]

5 Conclusions

I have examined whether a DSGE model that accounts for the heterogeneity in contracts length can explain the reset inflation observed in the data. I have shown that a MC calibrated based on the Klenow and Kryvtsov (2008) dataset can readily account for the observed reset inflation. In the MC, there can be many sectors, each with a Calvo style contact.

This result contrasts with the findings reported by BKM. These authors argue that neither time dependent nor state dependent models can explain the observed reset inflation. I have shown that the difference in conclusions

[6] Recent work by Kara (2010) shows that, by using the GTE, a failure to use a model that has an empirically relevant distribution of contract lengths can significantly affect policy conclusions.

arise because BKM assume a distribution of contract lengths that is different to that observed in the data. The assumed distribution underestimates the share of flexible contracts in the U.S. economy.

These findings suggest that using a model that ignores the heterogeneity in contacts we have observed in the data can be extremely misleading and that using a model that can account for the distribution of contract lengths we observe in the data is crucial for explaining both firm-level behaviour and aggregate data.

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6 Appendix: The Model

6.1 Firms

A typical firm in the economy produces a differentiated good which requires labour as the only input, with a CRS technology represented by

$$Y_{ft} = A_{it} L_{ft} \tag{11}$$

where $a_{it} = \log A_{it}$ is a productivity shock in sector i and follows the $AR(1)$ process: $a_{it} = \rho_i a_{it-1} + \varepsilon_{it}$. $f \in [0, 1]$ is firm specific index. Differentiated goods $Y_t(f)$ are combined to produce a final consumption good Y_t. The production function here is CES and corresponding unit cost function P_t

$$Y_t = \left[\int_0^1 Y_{ft}^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, P_t = \left[\int_0^1 P_{ft}^{1-\theta} df \right]^{\frac{1}{1-\theta}} \tag{12}$$

The demand for the output of firm f is given by

$$Y_{ft} = \left(\frac{P_{ft}}{P_t} \right)^{-\theta} Y_t \tag{13}$$

The firm chooses $\{P_{ft,} Y_{ft}, L_{ft}\}$ to maximize profits subject to (11, 13), yields the following solutions for price, output and employment at the firm level given $\{Y_t, W_{ft}, P_t\}$.

$$P_{ft} = \frac{\theta}{\theta - 1} \frac{W_{ft}}{A_{it}} \tag{14}$$

$$Y_{ft} = \left(\frac{\theta}{\theta - 1}\right)^{-\theta} \left(\frac{W_{ft}}{A_{it} P_t}\right)^{-\theta} Y_t \tag{15}$$

$$L_{ft} = \left(\frac{\theta}{\theta - 1}\right)^{-\theta} \left(\frac{1}{A_{it}}\right) \left(\frac{W_{ft}}{A_{it} P_t}\right)^{-\theta} Y_t \tag{16}$$

Price is a markup over marginal cost, which depends on the wage rate (W_{ft}) and the sector specific productivity shocks.

6.2 Household-Unions

The representative household h has a utility function given by

$$U_h = E_t \left[\sum_{t=0}^{\infty} \beta^t \left[U(C_{ht}) + V(1 - H_{ht}) \right] \right] \tag{17}$$

where C_{ht}, H_{ht} are household $h's$ consumption and hours worked respectively, t is an index for time, $0 < \beta < 1$ is the discount factor, and $h \in [0, 1]$ is the household specific index.

The household's budget constraint is given by

$$P_t C_{ht} + \sum_{s^{t+1}} Q(s^{t+1} \mid s^t) B_h(s^{t+1}) \leq B_{ht} + W_{ht} H_{ht} + \Pi_{ht} - T_{ht} \tag{18}$$

where $B_h(s^{t+1})$ is a one-period nominal bond that costs $Q(s^{t+1} \mid s^t)$ at state s^t and pays off one dollar in the next period if s^{t+1} is realized. B_{ht} represents the value of the household's existing claims given the realized state of nature. W_{ht} is the nominal wage, Π_{ht} is the profits distributed by firms and $W_{ht}H_{ht}$ is the labour income. Finally, T_t is a lump-sum tax.

The first order conditions derived from the consumer's problem are as follows:

$$u_{ct} = \beta R_t E_t \left(\frac{P_t}{P_{t+1}} u_{ct+1} \right) \tag{19}$$

$$\sum_{s_{t+1}} Q(s^{t+1} \mid s^t) = \beta E_t \frac{u_{ct+1} P_t}{u_{ct} P_{t+1}} = \frac{1}{R_t} \tag{20}$$

$$X_{it} = \frac{\theta}{\theta - 1} \frac{V_L \left(1 - H_{it+s}\right)}{\left[\frac{u_c(C_{t+s})}{P_{t+s}}\right]} \tag{21}$$

Equation (19) is the Euler equation. Equation (20) gives the gross nominal interest rate. Equation (21) shows that the optimal wage in sector i (X_{it}) is a constant "mark-up" over the ratio of marginal utilities of leisure and marginal utility from consumption. Note that the index h is dropped in equations (19) and (21), which reflects our assumption of complete contingent claims markets for consumption and implies that consumption is identical across all households in every period ($C_{ht} = C_t$).

Using (14), aggregating for firm f in sector i, substituting out for W_{it} in the resulting equation using the optimal labour supply condition (21), using the labour demand function (16) to substitute out for L_{it} and log-linearizing the resulting equation, I obtain the price level when prices are full flexible

$$p_{it}^{*} = p_t + \frac{\left(\eta_{cc} + \eta_{LL}\right)}{(1 + \theta\eta_{LL})} y_t - \frac{(1 + \eta_{LL})}{(1 + \theta\eta_{LL})} z_{it} \tag{22}$$

Note that the optimal flex price in each sector is the same.

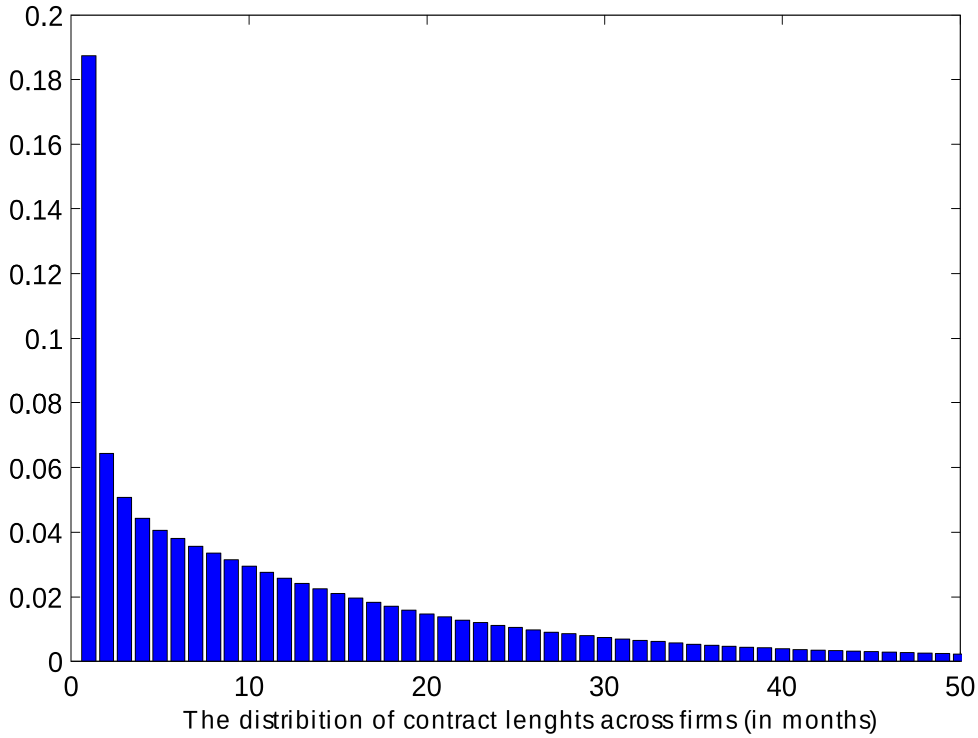

Figure 1: KK-distribution

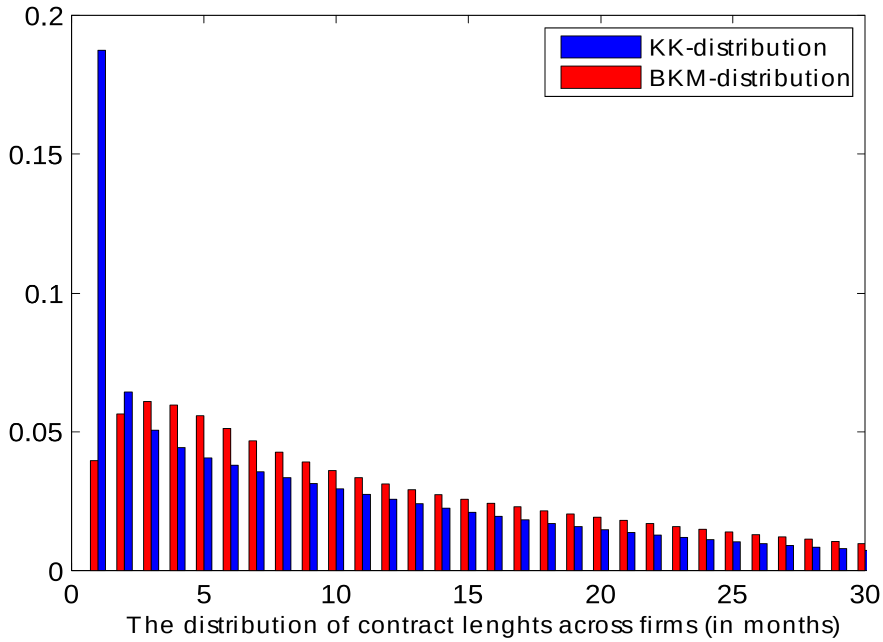

Figure 2: BKM-distribution vs. KK-distribution