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Product Cycles and Prices: Search Foundation *

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Abstract

This paper develops a price model with search foundation based on product cycles and prices. Observations conclude that firms match with a new product, then set a new price with negotiation and fix the price until the product exits from a market. This evident behavior brings a new model of price stickiness as a Search-based Phillips curve. The model includes a New Keynesian Phillips curve with the Calvo mechanism as a special case and describes new features. First, new parameters related to product entry and product exit play important roles for price dynamics. Second, such parameters for price stickiness directly appear on an expected price and lagged price.

Keywords: Phillips curve; search and matching

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1 Introduction

> "We have all visited several stores to check prices and/or to find the right item or the right size. Similarly, it can take time and effort for a worker to find a suitable job with suitable pay and for employers to receive and evaluate applications for job openings. Search theory explores the workings of markets once facts such as these are incorporated into the analysis. Adequate analysis of market frictions needs to consider how reactions to frictions change the overall economic environment: not only do frictions change incentives for buyers and sellers, but the responses to the changed incentives also alter the economic environment for all the participants in the market. Because of these feedback effects, seemingly small frictions can have large effects on outcomes."
>
> Peter Diamond

> "Price dynamics in imperfectly competitive markets result from the interplay of sellers' and buyers' strategies. Understanding the microeconomic determinants of price setting and their welfare or macroeconomic implication - such as the role of friction in monopolistic competition or the effects of inflation - therefore requires an analysis which incorporates the decision problems of both types agents. With this in mind, this paper brings together two hitherto separated, but highly complementary, strands of the imperfect competition literature, namely optimal price adjustment and search model."
>
> Roland Benabou

Recent observations from microdata reveals facts for product cycles and prices. We have revealed a new simple story for price stickiness. Firms match with new products, then set new prices with negotiation and fix prices until the product exits from a market.

Broda and Weinstein (2010) show that product turnover rate at the product level in the United States is about 25 percent annually for product entry and exit. This result implies that all products change every four years. They also show that these product cycles holds a significant effect on a price index. Nakamura and Steinsson (2012) sheds light on product turn over being a key mechanism for price adjustment, a discussion of so called product replacement bias. They also show that 40 percent of products are replaced without price change and 70 percent are replaced with two or less price changes after the introductions of goods into markets in raw microdata for trade price indexes. Ueda, Watanabe, and Watanabe (2016) confirm the same facts for Japan using the POS scanner data. They reveal that a product turnover rate is 30 percent annually. Price adjustment occurs in timing of product turnover and more than half of products do not experience price changes until their exit from the market. These facts indicate that a product cycle and fixed price after entry make price stickiness.[1]

On the other hand, to capture price stickiness, a large number of papers for the New Keynesian Phillips Curve assume the Calvo (1983) - Yun (1996) price adjustment in which firms optimally change prices with a certain probability. Their price adjustment mechanism provides a great proxy for price stickiness. Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007) show that this New Keynesian Phillips Curve based on Calvo (1983) - Yun (1996) price adjustment well fit to data. Thanks to tractability capturing a distortion of price dispersion, optimal monetary policy analysis also start with the New Keynesian Phillips Curve with Calvo (1983) - Yun (1996) price adjustment as shown in Woodford (2003). Those analyses justify a key feature of monetary policy in last few decades, i.e., inflation stabilization as an optimal criteria for monetary policy. However, it is a problem of Calvo (1983) - Yun (1996) price adjustment that does not explicitly express any concrete story for price stickiness. Thus, New Keynesian Phillips Curve can show a different form and implications for monetary policy when we introduce a specific situation regarding price stickiness.

There are several trials to replace the New Keynesian Phillips Curve with the Calvo (1983) - Yun (1996) price adjustment by alternative price models with explicit mechanisms for price stickiness. Mankiw and Reis (2002) build up a sticky-information model. They assume that information diffusion is slow and information updating is costly to reset goods price. In contrast to a New Keynesian model, a sticky-information model includes an infinite sum of expectation for a present inflation rate that has a sufficient persistence of inflation rate. Gertler and Leahy (2008) develop a tractable state dependent Phillips curve in contrast to a time dependent Phillips curve based on the Calvo mechanism. They assume that firms being in a state to get benefit over cost optimally

[1]Cavallo, Neiman, and Rigobon (2014) show that most products do not change their prices in their lifetime using online prices data after first prices into markets.

reset new price. This Phillips curve with an Ss foundation holds the same form as the New Keynesian Phillips Curve. Only a difference between two Phillips curves is a larger response to demand reflecting greater flexibility of price adjustment in the Phillips curve with an Ss foundation.[2]

In sharply contrast to these studies, we propose a new alternative for a model of price stickiness following new observations in micro data. This paper explicitly sets up the situation of infrequent price adjustment using a search and matching procedure. Firms newly match with demand and supply of new products in the goods market and they negotiate the price of a new goods. Firms matched from a previous period with old goods do not change price. This infrequent price adjustment follows the spirit of Shimer (2004) and Hall (2005) in a labor market on a basis of the search theory of Mortensen and Pissarides (1994).

There are several studies for search and match in a goods market though these papers do not investigate the role of price in a goods market. In terms of trade, Drozd and Nosal (2012) introduce search and matching into goods trade between countries in a model to solve puzzles regarding the correlation of real export and import prices and the volatility of the real exchange rate. Eaton, Jinkins, Tybout, and Xu (2016) assume a search and matching process for international buyer-seller connections for goods to explain various empirical issues. These papers imply the validity of search and match for a goods market.

Empirical studies, such as Barrot and Sauvagnat (2016), show that there exist search and match frictions in production networks using firm level data. They find that the occurrence of natural disasters on suppliers reduces output on their customers when these suppliers produce specific input goods and justify that specific input goods are not traded in a centralized market that does not need search frictions. Carvalho, Nirei, Saito, and Tahbaz-Salehi (2016) also show that individual firms can not quickly find suitable alternatives under a decentralized goods market with search friction when firms are faced with a supply-chain disruption by a natural disaster in Japan. They also show that a

[2] Also, see Woodford (2009) that shows a similarity and difference between a state dependent pricing model and a time dependent pricing model under limited information.

disruption of the micro supply chain is a key driver of macro aggregated fluctuations.

2 The Search-based Phillips Curve

We start with a single price model with negotiation for a price between two types of firms under a search and match process in a goods market. We cut a part of a product chain and show a detail of a price setting.

2.1 Negotiation between Firm A and Firm B

For price setting, two types of firms, firms A and firms B, negotiate goods price in a search and matching market. Firms A are identical except a timing for matching with firms B and firms A exist infinite number of a measure one and so do firms B. Firm B can be either a productive firm or a seeker firm for goods, where a number of seeker is given by u_t. A productive firm produces Z units of goods B. To be productive, a firm must obtain g real units of goods A from firms A.

A goods market for goods A is characterized by search frictions, and the flow cost of searching for a vacancy is $\kappa > 0$ paid by firms B. With probability p_t^F, a seeker firm B is matched with a firm A. Firm B then receives g units of goods A, produces Z of goods B, give it to the next agent in a chain of goods, and pay back $\widetilde{P}_t^I g$ to firm A. We assume that a price of goods B is constant at one for simplicity.[3] Finally, at the end of period t, a product chain is dissolved with probability $\rho \in (0, 1)$, in which case firm A and B separate and search for new matches for production and price setting in the next period $t + 1$. With probability $1 - \rho$, a contract survives and the firm B again receives goods A in period $t + 1$. We call ρ the separation rate.

Here, aggregate price P_t^I for goods A is determined by firm A and B through the sequence of Nash negotiation. Moreover, a new price $\widetilde{P}_t^I$ for goods A is set by only newly matched firms following the spirit of Shimer (2004) and Hall (2005) as shown in following

[3] We introduce a price for goods B in several ways in following sections.

sections.[4]

There is free entry into a market of goods A. Thus, in equilibrium, the value of a seeker firm is zero, and hence the cost of searching must equal the expected revenue, or

$$\kappa = \beta p_t^F \mathrm{E}_t W_{t+1}(\widetilde{P}_{t+1}^I). \tag{1}$$

Here, $W_t(\widetilde{P}_t^I)$ is the value of a productive firm B as

$$W_t(\widetilde{P}_t^I) = Z - g\widetilde{P}_t^I + \beta(1-\rho)\mathrm{E}_t W_{t+1}(\widetilde{P}_t^I). \tag{2}$$

The first two terms on the right-hand side (RHS) of equation (2) show the net current profit from production, while the third term is the discounted present value of future profit.

From equations (2), we have

$$W_t(\widetilde{P}_t^I) = \frac{1}{1-\beta(1-\rho)}\left[Z - g\widetilde{P}_t^I\right]. \tag{3}$$

Firm A produces goods A using an exogenous resource with a cost. This resource can include a labor input through a production function even though we do not specify it in this stage. To search for seeker of firm B, firm A must post offers, which we call "vacancies". Posting vacancies is costless, but total goods production by firm A is capped at gL^* due to a limit of technology of L^*.[5]

Therefore, the number of vacancies v_t is expressed as

$$v_t = L^* - (1-\rho)L_t, \tag{4}$$

where L_t is the number of firms A. In period t, a vacancy is filled with probability q_t^I. Thus, L_t evolves according to

$$L_{t+1} = (1-\rho)L_t + q_t^I v_t. \tag{5}$$

[4] We can also assume that matched firms from a previous period index their contracted price to the inflation rate as an extension.

[5] As an extension, we can make production limit of L^* an endogenous variable by introducing a variety of goods as in Bilbiie, Ghironi, and Melitz (2012).

In such settings, the value of a new match for a firm A is

$$J_t^1(\widetilde{P}_t^I) = g\widetilde{P}_t^I - X_t + \beta \mathrm{E}_t \left[(1-\rho) J_{t+1}^1(\widetilde{P}_t^I) + \rho J_{t+1}^0 \right], \tag{6}$$

where X_t is an exogenous cost for production. The first term on the RHS shows current profit from sales, while the second term represents the discounted present value of a future profit.

On the other hand, the value of a vacancy for a firm A is

$$J_t^0 = \beta \mathrm{E}_t \left[q_t^I J_{t+1}^1(\widetilde{P}_{t+1}^I) + (1-q_t^I) J_{t+1}^0 \right]. \tag{7}$$

Since a vacancy yields no current profit, it has only discounted future values. These two equations imply that the surplus of a firm A from a new match is

$$J_t^1(\widetilde{P}_t^I) - J_t^0 = g\widetilde{P}_t^I - X_t + \beta \mathrm{E}_t \left\{ (1-\rho) \left[J_{t+1}^1(\widetilde{P}_t^I) - J_{t+1}^0 \right] - q_t^I \left[J_{t+1}^1(\widetilde{P}_{t+1}^I) - J_{t+1}^0 \right] \right\}, \tag{8}$$

and so

$$\begin{aligned} J_t^1(\widetilde{P}_t^I) - J_t^0 = {} & \frac{g}{1-\beta(1-\rho)} \widetilde{P}_t^I - \beta(1-\rho) \frac{g}{1-\beta(1-\rho)} \mathrm{E}_t \widetilde{P}_{t+1}^I - X_t \\ & + \beta \mathrm{E}_t \left[(1-\rho-q_t^I)(J_{t+1}^1(\widetilde{P}_{t+1}^I) - J_{t+1}^0) \right]. \end{aligned} \tag{9}$$

Note that price is determined by the future condition and a matching condition at present. Thus, price decision is forward-looking.

2.2 Goods Market with Search Friction

The number of new matches in a period is given by a Cobb-Douglas matching function

$$m(u_t, v_t) = \chi u_t^{1-\alpha} v_t^{\alpha}, \ \ \chi, \alpha \in (0,1). \tag{10}$$

Defining supply and demand for goods A in a market as

$$\theta_t = \frac{u_t}{v_t}, \tag{11}$$

we obtain

$$p_t^F = \chi \theta_t^{-\alpha}, \tag{12}$$

$$q_t^I = \chi \theta_t^{1-\alpha}, \tag{13}$$

$$L_{t+1} = (1-\rho)L_t + \chi \theta_t^{1-\alpha} v_t. \tag{14}$$

The price of goods A is determined according to Nash bargaining between the newly matched firm A and firm B. Thus, $\widetilde{P}_t^I$ solves

$$\max_{\widetilde{P}_t^I} W_t(\widetilde{P}_t^I)^{1-b}(J_t^1(\widetilde{P}_t^I) - J_t^0)^b, \tag{15}$$

where $b \in (0,1)$ is the bargaining power for firm A. The first-order condition with respect to $\widetilde{P}_t^I$ yields

$$bW_t(\widetilde{P}_t^I) = (1-b)(J_t^1(\widetilde{P}_t^I) - J_t^0). \tag{16}$$

The aggregate price P_t^I of goods A is given by

$$L_t P_t^I = (1-\rho)L_{t-1}P_{t-1}^I + \chi \theta_{t-1}^{1-\alpha} v_{t-1} \widetilde{P}_t^I. \tag{17}$$

2.3 Linearized Price Equation

Linearized price equations are convenient to reveal the features of price dynamics. We log-linearize the price equations around a constant steady-state equilibrium. We express the log-deviation of a variable (e.g., P_t) from its efficient steady-state value ($\bar{P}$) by placing a hat ($\widehat{\ }$) over the lower case symbol ($\widehat{p}_t$).

Linearized price dynamic equations are given by equations (1), (3), (9), (12), (13), (16), and (17) as[6]

$$\widehat{\widetilde{p}}_t^I = \beta \left(1 - \rho - \bar{q}^I \frac{b}{\alpha}\right) \mathrm{E}_t \widehat{\widetilde{p}}_{t+1}^I + (1-b)\left[1 - \beta(1-\rho)\right] \frac{\bar{X}}{g} \widehat{X}_t, \tag{18}$$

$$\widehat{p}_t^I = (1-\rho)\widehat{p}_{t-1}^I + \rho \widehat{\widetilde{p}}_t^I. \tag{19}$$

From these two equations, we have

$$\pi_t^s = \beta \left(1 - \rho - \bar{q}^I\right) \mathrm{E}_t \pi_{t+1}^s + \gamma^X \widehat{X}_t, \tag{20}$$

where we define an adjusted inflation rate $\pi_t^s \equiv \widehat{p}_t^I - (1-\rho)\widehat{p}_{t-1}^I$ and $\gamma^X \equiv \rho(1-b)\left[1 - \beta(1-\rho)\right] \frac{\bar{X}}{g}$ and we assume the Hosios (1990) condition, that is, the bargaining

[6]For simplicity, we assume that a steady-state price is one.

power, i.e., b, equals the elasticity of the matching function with respect to vacancies, i.e., α. Equivalently in price level,

$$\widehat{p}_t^I = \gamma^f \mathrm{E}_t \widehat{p}_{t+1}^I + \gamma^b \widehat{p}_{t-1}^I + \gamma_{level}^X \widehat{X}_t, \tag{21}$$

where $\gamma^f \equiv \frac{\beta(1-\rho-\bar{q}^I)}{1+\beta(1-\rho)(1-\rho-\bar{q}^I)}$, $\gamma^b \equiv \frac{1-\rho}{1+\beta(1-\rho)(1-\rho-\bar{q}^I)}$, and $\gamma_{level}^X \equiv \rho(1-b)\frac{1-\beta(1-\rho)}{1-\rho-\bar{q}^I}\frac{\bar{X}}{g}$.

These equations are a price dynamic equation in a goods market with search and match. We call these equations as a Search-based Phillips curve. This curve shows several features for price dynamics. The present price is determined by three elements, lagged price, expected price, and exogenous cost of production. Expected price is included in the equation due to infrequent price change in a forward-looking behavior as shown in equations (8) and (9). A lagged price is included since an aggregate price is given by the weighted sum of new price and the unchanged price of survival goods from a previous period as shown in equation (17). When these expected price and lagged price increase, a present price increase. An exogenous cost term is included from equation (6). When a cost of production increase, a price increases. Moreover, parameters related to a product cycle are included in the curve. A product exit rate ρ appears directly on an expected price and a lagged price. Coefficients for these terms become smaller as a product exit rate becomes larger since price change occurs more frequently and price setting depends more on a present cost of production. A probability of match in a market, i.e., $\bar{q}^I$, also appears on an expected price and a lagged price. When a matching probability increases, a coefficient for an expected price decreases but a coefficient for a lagged price increases.

3 Search-based and New Keynesian Phillips Curves

To introduce a price stickiness, a large number of papers for New Keynesian models assume the Calvo (1983) - Yun (1996) price adjustment in which firms optimally change price with a certain probability. As shown in Woodford (2003), a price equation is given by

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \frac{(1-\xi)(1-\beta\xi)}{\xi} \mu_{mc} \widehat{mc}_t, \tag{22}$$

where ξ is a so called Calvo parameter that decides the probability of no price adjustment, μ_{mc} is a positive parameter that is a part including other parameters other than the Calvo parameter, $\pi_t \equiv \widehat{p}_t^I - \widehat{p}_{t-1}^I$, and $\widehat{mc}_t$ is a marginal cost in production that corresponds to cost for production of X_t in a search model.[7] This is a so called New Keynesian Phillips curve. Note that price setting becomes more frequent and a price response to a marginal cost becomes stronger as ξ becomes smaller.[8]

Coefficients on prices in a Search-based Phillips curve and the New Keynesian Phillips curve show a similar form when ρ and $\bar{q}^I$ are sufficiently small. This fact implies that the New Keynesian Phillips curve is a special case of the Search-based Phillips curve when product turnover is sluggish in a goods market. Behind the Calvo (1983) - Yun (1996) price adjustment, there is a state of infrequent price adjustment by search and matching.

Figure 1 shows impulse responses of the inflation rate to a negative shock with persistence of 0.5 in price models.[9] The parameters used in simulations are in Table 1. The discount rate β in quarter is given by 0.99 as a conventional value. We change ρ from 0.0625 to 0.25 that correspond to from 4 years to 1 year in turnover cycles, respectively. A case of 4 years in turnover cycle, i.e., $\rho = 0.0625$, is a finding of Broda and Weinstein (2010). They show that product turnover rate at the product level in the United States is about 25 percent annually for product entry. Thus, price is constant for 4 years if the price does not change after entry to the market.[10] The figure also includes cases of the New Keynesian Phillips curve. We assume the same shock in simulations and thus replace terms of production costs with parameters by the same shock.[11]

[7]According to models, μ_{mc} takes different values as shown in Woodford (2003).

[8]In a price level, we have

$$\widehat{p}_t^I = \frac{\beta}{1+\beta} \mathrm{E}_t \widehat{p}_{t+1}^I + \frac{1}{1+\beta} \widehat{p}_{t-1}^I + \frac{(1-\xi)(1-\beta\xi)}{\xi(1+\beta)} \mu_{mc} \widehat{mc}_t. \tag{23}$$

[9]Note that there is a closed system of an economy behind a Search-based Phillips curve. So, we can calculate dynamics of other variables in a search model in simulations.

[10]We can alternatively assume that price changes according to indexation after entry to the market.

[11]In details, we have $\frac{(1-\xi)(1-\beta\xi)}{\xi(1+\beta)} \mu_{mc} \widehat{mc}_t = \rho(1-b) \frac{1-\beta(1-\rho)}{1-\rho-\bar{q}^I} \frac{\bar{X}}{g} \widehat{X}_t = z_t$, where z_t is a shock.

The figure shows that the Search-based Phillips curve and the New Keynesian Phillips curve show similar inflation rate dynamics when a separation rate is small. When product turnover cycle is longer than 2 years, Search-based Phillips curves sufficiently replicate price dynamics by the New Keynesian Phillips curve. For less than a one year product cycle, a Search-based Phillips curve shows smaller and shorter responses to the shock. Among cases of Search-based Phillips curves, as a separation rate becomes larger, persistence of an inflation rate naturally becomes shorter. This is because firms more frequently change price.

On the other hand, as a nature of the New Keynesian Phillips curve, the dynamics of the inflation rate does not change even when a deep parameter for infrequent price adjustment changes since the coefficients on inflation rates only include the discount rate and exclude a parameter of infrequent price adjustment. In the New Keynesian Phillips curve, the coefficient on the consumption gap includes a parameter for price stickiness and changes price dynamics. This is sharply in contrast to the Search-based Phillips curve in which a parameter deciding price change appears on an expected price and explicitly influences the price dynamics.

4 Future Extension

There is a great possibility to extend a Search-based Phillips curve. For future extension, we evaluate a performance of Search-based Phillips curve in a rich general equilibrium model. We can introduce a relationship among multiple prices, such as a wholesale price and a consumption price. It would be also of interest to show optimal criteria for a model with a Search-based Phillips curve. Moreover, we can extend a model to include multiple search and match processes in a product chain and evaluate these effects on price dynamics. In particular, roles of domestic and international product chains should be focused.

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Table 1: Parameter Values

Parameters	Values	Explanation
β	0.99	Discount Factor
ρ	0.0625	Product Entry Rate
$\bar{q}^I$	0.0625	Probability of Filling Vacancy in Steady State

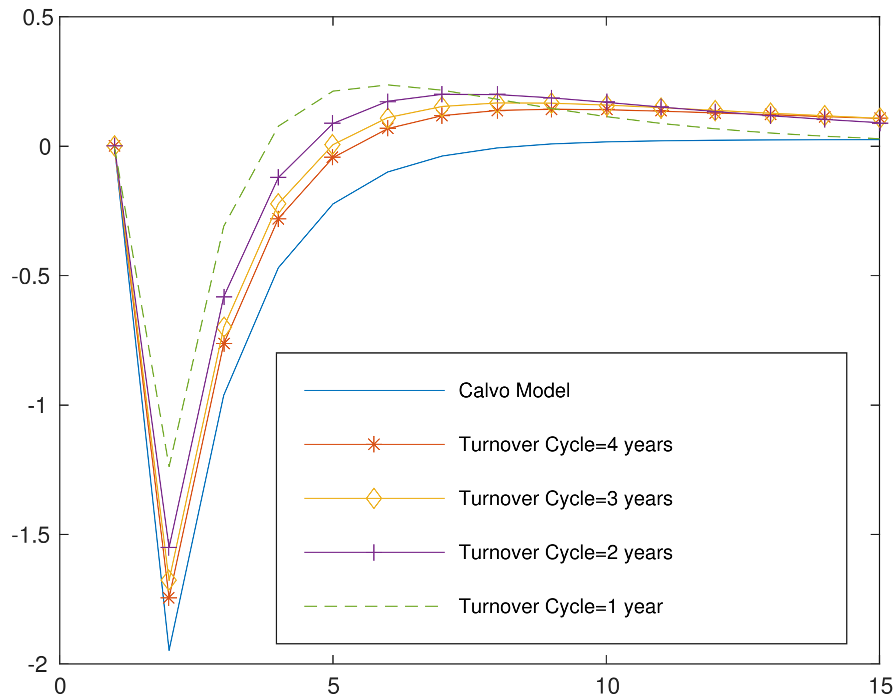

Figure 1: Response of Inflation Rate