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Menu Costs and Inflation Asymmetries

Some Micro Data Evidence

PÉTER KARÁDI – ÁDÁM REIFF

INSTITUTE OF ECONOMICS, HUNGARIAN ACADEMY OF SCIENCES
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Abstract

The paper explains the observed asymmetric inflation response to value-added tax (VAT) changes in Hungary by calibrating a standard sectoral menu cost model on a new micro-level CPI data set. The model is able to reproduce important moments of the data, and finds that the asymmetry can be explained by the interaction of menu costs, (sectoral) trend inflation and forward-looking firms, thereby it provides direct evidence to the argument of Ball and Mankiw (1994).

JEL: E 30

Keywords:

Menu Cost, Inflation Asymmetry, Sectoral Heterogeneity, Value-Added Tax

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Menüköltségek és inflációs aszimmetria
Elemzés mikroadatokon

Karádi Péter - Reiff Ádám

Összefoglaló

A tanulmány a hazai általános forgalmi adó változások aszimmetrikus inflációs hatását magyarázza meg egy szektorszintű menüköltség modell felhasználásával. A modell költséges árváltoztatást és jelentős mértékű termékszintű sokkokat tételez fel, és ezáltal sikeresen reprodukálja a termékszintű áradatokban megfigyelt árváltoztatási gyakoriságot és az árváltoztatások átlagos méretét is. A tanulmány alapvető megállapítása, hogy az aszimmetriát elsősorban a pozitív szektorszintű trend infláció okozza: az előretekintő cégek nemcsak az adóváltozás közvetlen hatását, hanem a várható szektorszintű infláció hatásait is érvényesítik az áraikban, ami nagyobb pozitív és kisebb negatív inflációs hatást eredményez. A tanulmány így közvetlen bizonyítékkal szolgál Ball és Mankiw (1994) elméleti érveléséhez.

Tárgyszavak:

Menüköltség, Inflációs aszimmetria, Szektorális heterogenitás, Általános forgalmi adó

Menu Costs and Inflation Asymmetries
Some Micro Data Evidence*

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October 18, 2007

Abstract

The paper explains the observed asymmetric inflation response to value-added tax (VAT) changes in Hungary by calibrating a standard sectoral menu cost model on a new micro-level CPI data set. The model is able to reproduce important moments of the data, and finds that the asymmetry can be explained by the interaction of menu costs, (sectoral) trend inflation and forward looking firms, thereby it provides direct evidence to the argument of Ball and Mankiw (1994).

Keywords: Menu Cost, Inflation Asymmetry, Sectoral Heterogeneity, Value-Added Tax

JEL Classification: E30

1 Introduction

Asymmetric inflation response to symmetric aggregate shocks is an important indirect evidence supporting models with sticky prices. While standard frictionless, flexible price models do not explain it, asymmetry is a straightforward prediction of sticky price models with positive trend inflation. The reason of this, as it was first argued by Ball and Mankiw, 1994, is that forward looking firms setting their prices for several periods will incorporate the effects of the positive trend inflation; they are going to be more responsive and be willing to change their prices by a larger absolute magnitude for a positive shock than to negative one. [1]

*Work in progress, comments are welcome. The authors would like to thank Peter Benczur, Laszlo Halpern, Attila Ratfai and seminar participants at the Summer Workshop of the Institute of Economics, Hungarian Academy of Sciences and the National Bank of Hungary for insightful comments. All errors remain ours. The views expressed are those of the authors and do not necessarily reflect the views of the National Bank of Hungary.

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[1] In a similar framework, Devereux and Siu, 2007 provide a different argument for asymmetry by showing that individual firms' strategic incentives are asymmetric: while prices are strategic complements in case of positive aggregate shocks to the (nominal) marginal cost, they are strategic substitutes in case of negative shocks. This strategic asymmetry is found to be larger with more intense competition (higher elasticity of substitution parameter θ). In their result, however, the asymmetry is of third-order and, in our simulations, even with relatively high elasticity of substitution parameter $\theta = 11$, the 4% tax changes were not large enough to make this effect significant (zero inflation rate still implied symmetric inflation responses).

The paper sets out to examine the asymmetry on a new comprehensive CPI data set of Hungary, capitalizing on the natural experiment provided by the two major value added tax (VAT) increases and a major tax decrease between 2004 and 2006.[2] These VAT shocks provide exceptional information about the pricing behavior of firms[3], as these exogenous cost push shocks influence a large number of firms simultaneously in an easily measurable way. Gabriel and Reiff, 2007 using the same data set found that the shocks had asymmetric aggregate inflation effect (see Figure 1). According to the estimates, while the 2006 September 5%-points increase of the 15% VAT rate[4] increased the sample CPI by 2.13%, the 2006 January 5%-points decrease of the 25% VAT rate[5] decreased the CPI only by 0.92%. The asymmetry is even more pronounced in the subsamples of products directly affected by the tax changes: their average price increase was 3.73% for the VAT increase and only -1.24% for the VAT decrease.

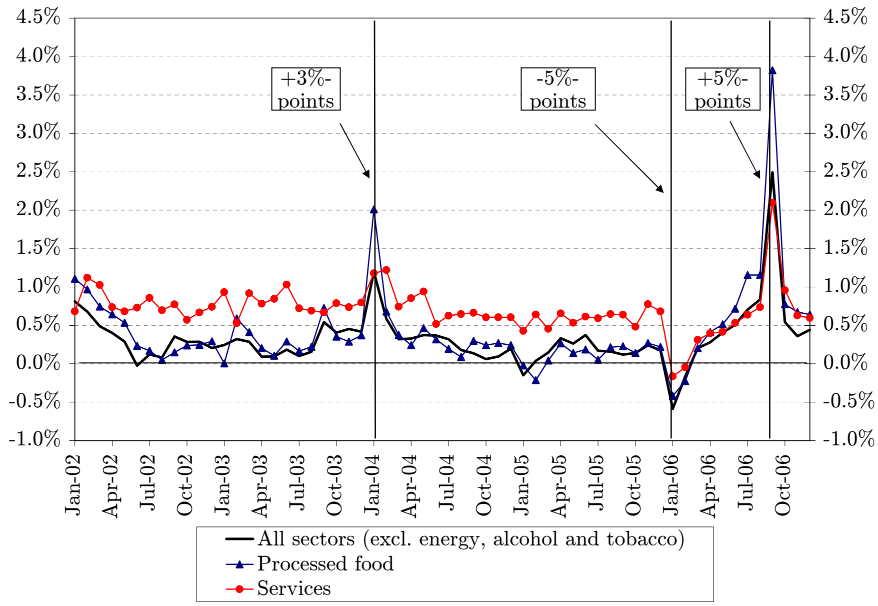

Figure 1: Monthly inflation rates and VAT rate changes (sample averages)

The paper calibrates a standard sectoral menu cost model of Klenow and Willis, 2007 with idiosyncratic shocks to reproduce important moments of the data, like inflation rate (Figure 1), the fraction of price changing firms (see Figure 2 later) and magnitude of price changes (see Figure 3 later), and examines whether the asymmetry implied by the model is in line with that observed in the data.

Menu cost models assume that firms face a small fixed cost for changing their prices

[2]In this version of the paper, we are going to concentrate on the 2006 January 5% points tax decrease and the 2006 September 5% points tax increase.

[3]Especially in Hungary, where most sectors quote gross prices.

[4]Influencing 46.9% of the products in our sample.

[5]Influencing another 51%.

implying lumpy price adjustments in line with direct price-spell observations: prices, in general, are constant for many months (the average duration of a price spell in Hungary is 9.5 months). Adding idiosyncratic technology shocks to the model, as suggested by Golosov and Lucas, 2003, is necessary to explain the average size of price changes, which are much higher (11.5% in our sample) than that justified by the average inflation rate (3.9%).

The application of a 'state-dependent' menu cost model is also justified by the development of the fraction of price-changing firms (see Figure 2 later). Standard 'time-dependent', Calvo-style models assume exogenous probability of price changes, and even though this would be in line with the relatively constant frequency of price changing firms in 'normal' months (12% in our sample), it would be unable to account for the increased frequency of price changing firms at the months of VAT shocks clearly observable in the data (31.4%).

The paper differentiates among major sectors in the economy and uses different calibrations for each of them. We can observe substantial heterogeneity both in terms of inflation rates and the level of price-stickiness among sectors, and as firms can be expected to pay more attention to the sectoral price developments where most of their competitors are, using a sectoral model is more appropriate. Furthermore, this choice allows us to control for the different sectoral composition of the observed tax changes. The VAT increases and the decrease affected various sectors differently, the VAT increase hitting sectors with more flexible prices disproportionally, providing some explanation for the observed asymmetry.

Though some arguments might be given that menu costs or (the logarithm of) idiosyncratic productivity shocks are asymmetric, this paper does not assume any asymmetry in the micro level. Neither the narrow definition of menu costs as the physical costs of changing a price nor a broader definition as information collection and decision costs would imply asymmetric costs for a price increase or a price decrease.[6]

The model is able to hit important moments of the data. By setting reasonable parameter values the model is able to hit both the average frequency and the magnitude of the price changes. Furthermore, the model has no problem reproducing the stylized fact that price increases are usually more frequent but *smaller* than price decreases, contrary to the original Ball and Mankiw, 1994 model which predicted more frequent, and *larger* price increases. The reason of the difference is that while Ball and Mankiw, 1994 assume symmetric profit functions, the standard constant elasticity of substitution (CES) utility function results in asymmetric profit and value functions. The asymmetry comes from the fact that lower relative price implies higher demand, so higher relative losses from a suboptimal price. As a result of this asymmetry, the firms are going to be more sensitive to their relative price being smaller than the optimal than when it is higher, and be ready to make smaller upward price adjustments.

The observed VAT shocks not just increased the fraction of price changing firms, but also *decreased* the average size of the price changes (see Figures 2 and 3). A standard model with homogeneous menu costs can not quantitatively explain this stylized fact, even though standard channels in menu costs models can give some explanation for the sign of these

[6]The introduction of sales, however, might give some justification to asymmetric menu costs. Midrigan and Kehoe, 2007 endogenize sales choice by assuming that the firms can choose to decrease the price of their product temporarily for a lower than normal menu cost, and show that their model can reproduce important characteristics of sales observed their micro-level data. It should be noted, though, that they increase *downward* flexibility on the micro-level influencing results contrary to the macro-evidence of downward price rigidity. Our model disregards sales and we filter it out from our data as well.

effects, especially if we consider that VAT shocks can be considered more persistent than other cost shocks justifying a lower threshold for price changes. The paper finds, however, that a lower menu cost at the months of VAT changes can reproduce both the frequency and the magnitude of price changes observed in the data. This fact might suggest that a (not explicitly modeled) more general definition of menu cost might be justified including not just physical costs – which are the same for any shocks –, but information collecting and decision making costs as well, which can be expected to be lower for the widely publicized, substantial and easily measurable VAT shock.

The main finding of the paper is that a sectoral menu cost model calibrated to hit the mean sectoral inflation rate and the level of price stickiness observable in the data can fully account for the sectoral asymmetry observed in the data for both of the two examined sectors in Hungary.[7] The paper also shows that a non-sectoral version of the model hitting the average inflation rate and the average level of price stickiness underestimates the asymmetry in the inflation responses underlining the necessity of a sectoral model to be able to explain the observed asymmetry.

There is a long line of research documenting asymmetric price developments to monetary and cost shocks using aggregate (see e.g. Cover, 1992, Ravn and Sola, 2004) and sectoral data (Peltzman, 2000) in reduced form estimations. Our paper is the first we know of, however, which uses VAT shocks to analyze the effects of the asymmetry, which is arguably a more easily measurable and identifiable shock than those used by the previous papers. The main contribution of the paper, is to calibrate a menu cost model using the detailed and comprehensive micro-level pricing data of Hungary, and to show that (sectoral) trend inflations can fully account for the observed asymmetry. As standard frictionless, flexible price models would have difficulty in explaining these asymmetries, our paper is also a contribution to the growing literature using natural experiments – like the effect of euro introduction to restaurant prices in Hobijn, Ravenna and Tambalotti, 2006 – and special environments – like the high inflation episodes in Mexico in Gagnon, 2007 – to provide evidence to the validity of the sticky price assumptions in general and menu cost models in particular.

The paper is organized as follows. Section 2 presents the model, solves for the flexible price case and explains the numerical algorithm used for the solution in case of positive menu costs. Section 3 presents the data and the moments the paper is about to match, and presents some stylized facts the data suggests. Section 4 presents the results for the non-sectoral and the sectoral calibrations and section 5 concludes.

2 The Model

The paper uses a version of Klenow and Willis, 2006 sectoral menu cost model with standard monopolistic competition and CES preferences. The model assumes no aggregate nominal uncertainty by considering exogenously given nominal aggregate output growth (consistent with a nominal income targeting policy) and assumes unit elasticity of substitution between sectoral aggregates implying constant nominal expenditure growth on the sectoral level as well. Though this assumption is somewhat restrictive, it makes the model much more tractable,

[7] The analyzed processed food and services sector – the two largest – were hit by both the tax increases and the tax decrease.

and allows us to concentrate on the endogenous inflation response to aggregate shock we are mostly interested in.

In order to realistically capture the effects of the VAT shocks, the paper introduces two distinct value added tax rates[8] into the model, and considers two types of firms in each sector producing (imperfect) substitute products, but facing different tax rates.

The model assumes that the firms determine correct linear beliefs about the development of the endogenous sectoral state variables as is assumed in Krusell and Smith, 1998, and it is going to be solved numerically by value function iteration over a discretized state space.

2.1 The consumer

The representative consumer is assumed to maximize the expected present value of his utility

$$\max_{\{C_{si}(t),L_s(t),M(t)\}} E\sum_{t=0}^{\infty}\beta^t\left(\log\left[C(t)\cdot\left(\frac{M(t)}{P(t)}\right)^{\nu}\right]-\sum_{s=1}^{S}\frac{\mu_s}{1+\psi_s}L_s(t)^{1+\psi_s}\right), \tag{1}$$

where the aggregate $C(t)$ and sectoral consumptions $C_s(t)$ are determined by

$$C(t)=\prod_{s=1}^{S}\left(\frac{C_s(t)}{\alpha_s}\right)^{\alpha_s},\quad C_s(t)=\left(\sum_{i=1}^{n_s}n_s^{-\frac{1}{\theta_s}}C_{si}(t)^{\frac{\theta_s-1}{\theta_s}}\right)^{\frac{\theta_s}{\theta_s-1}}$$

with sector-specific elasticities of substitution θ_s. The consumer is assumed to supply sector specific labor $L_s, s=1,\ldots,S$, and obtain utility from holding real money balances (M/P).

The consumer's periodic budget constraint is given by

$$\sum_{s=1}^{S}\sum_{i=1}^{n_s}P_{si}(t)C_{si}(t)+\sum B(t+1)+M(t+1)=R(t)B(t)+M(t)+\sum_{s=1}^{S}\tilde{w}_s(t)L_s+\tilde{\Pi}(t)+T(t), \tag{2}$$

where $P_{si}(t)$ is the gross price, $B(t)$ is a state dependent nominal asset (nominal Arrow-security) with state dependent gross return $R(t)$, $M(t)$ is the nominal money balance and $T(t)$ is a lump-sum transfer.

Let the aggregate $P(t)$ and the sectoral price level be given by

$$P(t)=\prod_{s=1}^{S}P_s(t)^{\alpha_s},\quad P_s(t)=\left(\sum_{i=1}^{n_s}\frac{P_{si}(t)^{1-\theta_s}}{n_s}\right)^{\frac{1}{1-\theta_s}}.$$

The consumer optimization implies that he will spend a constant α_s fraction of his nominal expenditures on the sectoral composite good, with his demand for it is given by

$$C_s(t)=\alpha_s\left(\frac{P_s(t)}{P(t)}\right)^{-1}C(t), \tag{3}$$

and his demand for individual good i from sector s is given by

$$C_{si}(t)=\frac{1}{n_s}\left(\frac{P_{si}(t)}{P_s(t)}\right)^{-\theta_s}C_s(t)=\frac{\alpha_s}{n_s}\left(\frac{P_{si}(t)}{P_s(t)}\right)^{-\theta_s}\left(\frac{P_s}{P}\right)^{-1}C(t). \tag{4}$$

[8] In our model without product inputs, value added tax and sales tax are equivalent.

The Euler equation of the consumer implies that the stochastic discount factor $\frac{1}{R(t+1)}$ is given by

$$\frac{1}{R(t+1)} = \beta \frac{P(t)C(t)}{P(t+1)C(t+1)}. \tag{5}$$

The labor supply equation in each sector $s = 1, \ldots, S$ is given by

$$\mu_s L_s(t)^{\psi_s} C(t) = \frac{\tilde{w}(t)}{P(t)}. \tag{6}$$

The money demand equation is going to be

$$\frac{M(t)}{P(t)} = \nu C(t) \frac{i(t)+1}{i(t)}, \tag{7}$$

where $i(t)$ is the nominal interest rate.

2.2 The government and the central bank

Denote $\tau_{si}(t)$ the value added tax (VAT) in sector s for good i. The log gross tax rates are assumed to follow a finite state Markov process, with transition probabilities $P^j, j = 1, 2$ implying persistent tax changes. The government is assumed to maintain a balanced budget every period:[9]

$$\sum_{s=1}^{S} \sum_{i=1}^{n_s} P_{si}(t) \frac{\tau_{si}(t)}{1+\tau_{si}(t)} C_{si}(t) = T^g(t). \tag{8}$$

The central bank is assumed to follow a nominal income targeting rule by maintaining a predetermined growth rate of the nominal aggregate output. The resulting extra money supply $M(t)$ in the economy is redistributed in a lump sum way

$$M(t) - M(t-1) = T^m(t), \tag{9}$$

where $T^m(t) + T^g(t) = T(t)$ the total transfer to the consumers.

2.3 The firms

The firms are maximizing the present value of their profits facing a small menu cost for changing their gross prices. We denote this cost $\tilde{\phi}(t) = \phi(t)\frac{P(t)Y(t)}{n}$, and, for analytical convenience, we assume that it is proportional to their revenue. We also allow this menu cost to be smaller for tax shocks than in case of a more general shock. Our reasoning is that tax shocks are widely publicized, easily measurable and sizeable cost shocks, so – even though the physical costs of changing prices are the same – the firms can be expected to spend less on informing consumers (and competitors) about the reasons of the price changes, on collecting information and making decisions.

In each sector, we distinguish two types of firms: there are n_s^1 number of firms with tax rate τ^1 and $n_s^2 = n_s - n_s^1$ number of firms with tax rate τ^2. By this, we are modeling the fact

[9] If the net prices P^n are taxed by τ VAT, then the gross price is $P = (1+\tau)P^n$, so the tax revenue equals $\tau P^n C = \frac{\tau}{1+\tau} PC$.

that firms face different VAT tax levels and the changes influenced only a subset of firms in each sector.

We assume that the firms use only labor to produce their differentiated good i in sector s and face idiosyncratic shocks A_{si} and sectoral technology shocks Z_s. The production functions of the firms are given by

$$Y_{si}^{j}(t) = Z_s(t)A_{si}(t)L_{si}^{j}(t)^{\eta}. \tag{10}$$

The growth rate of the sectoral productivity $g_{Zs}(t+1) = \log(Z_s(t+1)) - \log(Z_s(t))$ is assumed to follow a first order autoregressive process

$$g_{Zs}(t+1) - \mu_{g_{Zs}} = \rho_{g_{Zs}}\left(g_{Zs}(t) - \mu_{g_{Zs}}\right) + \epsilon_{g_Z s}(t+1), \tag{11}$$

where $\epsilon_Z(t) \sim N(0, \sigma_{g_{Zs}}^2)$ is a white noise growth shock. Similarly, the idiosyncratic productivity $\log A_{si}(t)$ is a first order autoregressive process:

$$\log A_{si}(t+1) = \rho_{A_s} \log A_{si}(t) + \epsilon_{A_{si}}(t+1), \tag{12}$$

where $\epsilon_{A_{si}}(t) \sim N(0, \sigma_{A_s}^2)$ is a white noise shock, and is independent of $\epsilon_{g_Z}(t)$.

This production function (10) implies an individual labor demand

$$L_{si}^{j}(t) = \left(\frac{Y_{si}^{j}(t)}{Z_s(t)A_{si}(t)}\right)^{\frac{1}{\eta}}, \tag{13}$$

which aggregates to a sectoral labor demand given by

$$L_s(t) = \sum_{i=1}^{n_s^1} L_{si}^1(t) + \sum_{i=n_s^1+1}^{n_s} L_{si}^2(t). \tag{14}$$

Each firm in sector s, producing good i and facing tax rate τ_s^j is assumed to maximize the expected discounted present value of their profits

$$\max E \sum_{t=0}^{\infty} \frac{1}{\prod_{q=0}^{t} R(q)} \tilde{\Pi}_{si}^{j}(t), \tag{15}$$

where the periodic profit level is given by

$$\tilde{\Pi}_{si}^{j}(t) = \frac{1}{1+\tau_s^j(t)} P_{si}^{j}(t) Y_{si}^{j}(t) - \tilde{w}(t)\left(\frac{Y_{si}^{j}(t)}{Z_s(t)A_{si}(t)}\right)^{\frac{1}{\eta}}. \tag{16}$$

Using the fact that in equilibrium the demand $Y_{si}^j = C_{si}^j$, equation (4) implies

$$\tilde{\Pi}_{si}^{j}(t) = \frac{1}{1+\tau_s^j(t)} \frac{1}{n_s} P_{si}^{j}(t) \left(\frac{P_{si}^{j}(t)}{P_s(t)}\right)^{-\theta_s} Y_s(t) - \tilde{w}(t)\left(\frac{\frac{1}{n_s}\left(\frac{P_{si}^{j}(t)}{P_s(t)}\right)^{-\theta_s} Y_s(t)}{Z_s(t)A_{si}(t)}\right)^{\frac{1}{\eta}}. \tag{17}$$

We are going to normalize the profit level by the average sectoral revenues

$$\Pi^j_{si}(t) = \frac{\tilde{\Pi}^j_{si}(t)n_s}{\alpha_s P(t)Y(t)}, \tag{18}$$

where we used equation (3) implying constant proportions of sectoral expenditures given by $\alpha_s P(t)Y(t)$. Let $p^j_{si}(t) = \frac{P^j_{si}}{P_s(t)}$ be the sectoral relative price, $w(t) = \frac{\tilde{w}(t)}{P(t)Y(t)}$ the normalized wage rate, and $\phi(t) = \frac{\tilde{\phi(t)}n_s}{\alpha_s P(t)Y(t)}$ the normalized menu cost. Let $\zeta(t) = w(t)\left(\frac{n_s^{\eta-1}Y_s(t)}{Z_s(t)}\right)^{\frac{1}{\eta}}$ be a sectoral cost factor. Substituting these variables into the normalized periodic profit function we get that

$$\Pi^j_{si}(p^j_i(t), A_i(t), \zeta(t), \tau^j(t)) = \frac{1}{1+\tau^j(t)}\left(p^j_{si}\right)^{1-\theta_s} - \left(p^j_{si}(t)\right)^{-\frac{\theta_s}{\eta}}\zeta_s(t)A_{si}(t)^{-\frac{1}{\eta}} - \phi(t). \tag{19}$$

Firms are assumed to know the current values of both the current exogenous state variables $(A_{si}(t), g_{Zs}(t), \tau^1(t), \tau^2(t), \phi(t))$ and endogenous state variables $(\pi_s(t), \zeta_s(t), \Gamma_s(t))$, where $\pi_s(t)$ is the sectoral inflation rate and $\Gamma_s(t)$ is the distribution of prices, when making their decision about their current price, and assumed to satisfy all demand on this price. The state variables of the system are denoted by $(p^j_{is,-1}, \Omega_{is})$, where $\Omega_{is} = (A_{si}, \pi_s, \zeta_s, g_{Zs}, \tau^1, \tau^2, \phi, \Gamma_s)$. Let the value function of the firms be

$$V^j\left(p^j_{is,-1}, \Omega_{si}\right) = \max_{\{C,NC\}}\left(V^{NC,j}\left(p^j_{is,-1}, \Omega_{is}\right), V^{C,j}\left(p^j_{is,-1}, \Omega_{is}\right)\right), \tag{20}$$

where the value function in case of no price change (NC) is given by

$$V^{NC,j}\left(p^j_{is,-1}, \Omega_{is}\right) = \Pi^j_{si}\left(\frac{p^j_{si,-1}}{1+\pi_s}, A_{si}, \zeta_s, \tau^j_s\right) + E\frac{1}{R}V\left(\frac{p_{si,-1}}{1+\pi_s}, \Omega'_{si}\right) \tag{21}$$

and the value function in case of price change is given by

$$V^{C,j}\left(p^j_{is,-1}, \Omega_{is}\right) = \max_{p^j_{si}} \Pi^j_{si}(p^j_{is}, A_{si}, \zeta_s, \tau^j_s) + E\frac{1}{R}V\left(p_{si}, \Omega'_{is}\right). \tag{22}$$

The next period sectoral distribution of prices $\Gamma_s(t+1)$ is, in general, a very complicated function of the last period price distribution $\Gamma_s(t)$ and the current distribution of the sectoral idiosyncratic technology distribution $\Lambda_s(t+1)$ and the development of the exogenous state variables $g_{Zs}(t+1), \tau^1(t+1), \tau^2(t+1), \phi(t+1)$:

$$\Gamma_s(t+1) = \Theta(\Gamma_s(t), \Lambda_s(t+1), g_{Zs(t+1)}, \tau^1(t+1), \tau^2(t+1), \phi(t+1)) \tag{23}$$

2.4 The equilibrium

We consider a closed economy dynamic general equilibrium with deterministic nominal growth rate and firms forming linear forecasts about the future values of the aggregate endogenous state variables in the spirit of Krusell and Smith, 1998. The equilibrium requires

1. The representative consumer maximizes his utility function (1) given his budget constraint (2) taking goods prices $\{P_{is}(t)\}$, the interest rates $R(t)$ and the sectoral wages $\{w_s\}$ as given.

2. The firms are assumed to maximize their value function (20), (21), (22) knowing the current values of the state variables and correctly predicting the development of the idiosyncratic shock (12), the sectoral technology shock (11), the taxes and the menu costs.

   Following Krusell and Smith, 1998, we assume that the firms – instead of calculating the whole next period distribution of prices given by equation (23) predict only the inflation rate – the aggregate moment they are interested in – using a linear equation:

$$\pi_s^f(t+1) = \gamma_1 + \gamma_2\pi_s(t) + \gamma_3\zeta_s(t) + \gamma_4 g_{Zs}(t) + \gamma_5 g_{\bar{\tau}}^+(t+1) + \gamma_6 g_{\bar{\tau}}^-(t+1) + \epsilon_\pi,\ \epsilon_\pi \sim N(0, \sigma_{\epsilon_\pi}) \quad (24)$$

   containing all the current sectoral state variables. The equation also contains the next period increase/decrease of the average tax rates $g_{\bar{\tau}}^{\pm}$. Although, we do not assume the firms having information about the next period tax rates, we assume that they have correct forecasts how a tax change would influence the next period inflation rate if it happened (which we are going to use for estimating the transition matrix). The forecasting error ϵ_π – incorporating errors resulting from ignoring the whole price distribution – is assumed to be orthogonal to the regressors.

   Given this forecasted inflation rate, the forecast for the sectoral output growth $g_{Y_s}^f(t)$ is given by

$$g_{Y_s}^f(t) = g_{PY} - \pi_s^f(t), \quad (25)$$

   and the sectoral cost parameter $\zeta_s^f(t)$ is

$$\log\zeta_s^f(t) = \log\zeta_s(t-1) + \frac{1}{\eta}g_{Y_s}^f(t) - \frac{1}{\eta}g_{Z_s}(t) + g_w^f(t), \quad g_w^f = \frac{\psi}{\eta}\left(g_Y^f(t) - g_Z(t)\right). \quad (26)$$

   The estimate for the expected wage growth uses the approximate result $\log L(t) \sim \frac{\psi}{\eta}(\log Y(t) - \log Z(t))$ using the individual labor demand (13) and the labor supply equation (6).

3. Aggregate nominal output level, and thereby sectoral nominal demand follows the process

$$\log(P(t+1)Y(t+1)) = \log(P(t)Y(t)) + g_{PY}, \quad (27)$$

   where g_{PY} is an exogenously given constant. The assumption substantially simplifies the analysis, allowing the paper to focus on firm level and sectoral incentives for responding to tax changes.

4. Market clearing in all the goods market $C_{si}(t) = Y_{si}(t)$,

5. Assets in zero net supply: $B(t) = 0$,

6. Equilibrium in the sectoral labor markets implying sectoral wages w_s equating sectoral labor demand and labor supply.

2.5 Flexible-price equilibrium

If the menu cost is zero, then nothing prevents stores from re-optimizing their price each month. In this case, there is an analytical solution of the model, which serves as a benchmark for the menu cost case.[10]

Solving the firms' profit maximization problem, it is easy to derive that the optimal relative price is

$$p_i^*(t) = \left(\frac{\theta \zeta(t)}{\theta - 1} \frac{1 + \tau_i(t)}{\eta A_i(t)^{1/\eta}} \right)^{\frac{\eta}{\theta + \eta - \theta\eta}}, \tag{28}$$

with $\zeta(t) = w(t) \left(\frac{n^{\eta-1} C(t)}{Z(t)} \right)^{\frac{1}{\eta}}$, and $w(t) = \frac{\widetilde{w}(t)}{P(t)C(t)}$ being the normalized nominal wage.

Then the optimal relative consumptions are $\frac{C_i^*(t)}{C(t)/n} = p_i^*(t)^{-\theta}$, which implies

$$C_i^*(t) = \left(\frac{C(t)}{n} \right)^{\frac{\eta - \theta\eta}{\theta + \eta - \theta\eta}} Z(t)^{\frac{\theta}{\theta + \eta - \theta\eta}} \left(\frac{\theta n w(t)}{(\theta - 1)\eta} \right)^{\frac{-\theta\eta}{\theta + \eta - \theta\eta}} \left(\frac{1 + \tau_i(t)}{A_i(t)^{1/\eta}} \right)^{\frac{-\theta\eta}{\theta + \eta - \theta\eta}}. \tag{29}$$

Aggregating these with the CES-aggregator $C(t) = \left[\sum_i n^{\frac{-1}{\theta}} C_i(t)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$, we can derive that

$$\frac{(\theta - 1)\eta}{\theta \zeta(t)} = \left[\sum_i n^{-1} \left(\frac{1 + \tau_i(t)}{A_i(t)^{1/\eta}} \right)^{\frac{\eta - \theta\eta}{\theta + \eta - \theta\eta}} \right]^{\frac{\theta + \eta - \theta\eta}{\eta - \theta\eta}} \equiv 1 + \overline{\tau}(t), \tag{30}$$

where the summation is a CES-aggregate of individual "effective" tax rates $\frac{1+\tau_i(t)}{A_i(t)^{1/\eta}}$, denoted as an average tax rate $1 + \overline{\tau}(t)$.

With this average tax rate we can write the optimal individual relative prices as

$$p_i^*(t) = \left[\frac{(1 + \tau_i(t)) / A_i(t)^{1/\eta}}{1 + \overline{\tau}(t)} \right]^{\frac{\eta}{\theta + \eta - \theta\eta}}, \tag{31}$$

and relative outputs as

$$\frac{C_i^*(t)}{C^*(t)/n} = \left[\frac{(1 + \tau_i(t)) / A_i(t)^{1/\eta}}{1 + \overline{\tau}(t)} \right]^{\frac{-\theta\eta}{\theta + \eta - \theta\eta}} \tag{32}$$

which says that the optimal relative prices and relative outputs are determined by the relative effective tax rates (i.e. the ratio of the individual effective tax rates $\frac{1+\tau_i(t)}{A_i(t)^{1/\eta}}$ and the average tax rate $1 + \overline{\tau}(t)$).

The wage rate will be determined on the labor market by making labor demand and supply equal. Labor supply can be derived from the consumers' maximization problem. Rewriting equation (6) leads to

$$L(t) = \left(\frac{\widetilde{w}(t)}{\mu P(t) C(t)} \right)^{\frac{1}{\psi}} = \left(\frac{w(t)}{\mu} \right)^{\frac{1}{\psi}}, \tag{33}$$

[10] Sectoral subscripts s are suppressed for notational convenience.

while the labor demand equation (13) can be written in this way:

$$L_i(t) = \left(\frac{C_i^*(t)}{Z(t)A_i(t)}\right)^{\frac{1}{\eta}} = \frac{(\theta-1)\,\eta}{\theta n w(t)\,[1+\overline{\tau}(t)]\,A_i(t)^{1/\eta}}\left[\frac{(1+\tau_i(t))\,/A_i(t)^{1/\eta}}{1+\overline{\tau}(t)}\right]^{\frac{-\theta}{\theta+\eta-\theta\eta}}. \quad (34)$$

Aggregate labor demand is the sum of individual demands. A little algebra shows that the equilibrium wage rate is

$$w(t) = \mu^{\frac{1}{1+\psi}}\left(\frac{(\theta-1)\eta}{\theta}\right)^{\frac{\psi}{1+\psi}}\left[\sum_i \frac{1}{1+\tau_i(t)}\frac{n^{-1}\left[(1+\tau_i(t))\,/A_i(t)^{1/\eta}\right]^{\frac{\eta-\theta\eta}{\theta+\eta-\theta\eta}}}{[1+\overline{\tau}(t)]^{\frac{\eta-\theta\eta}{\theta+\eta-\theta\eta}}}\right]^{\frac{\psi}{1+\psi}}, \quad (35)$$

where the last term is a weighted average of $\frac{1}{1+\tau_i(t)}$-s (the weights sum to 1 by the definition of $1+\overline{\tau}(t)$ in equation (30)), and can therefore be written as another average of individual tax rates: $\frac{1}{1+\widetilde{\tau}(t)}$. Therefore the equilibrium wage rate is simply

$$w(t) = \mu^{\frac{1}{1+\psi}}\left(\frac{(\theta-1)\eta}{\theta\,(1+\widetilde{\tau}(t))}\right)^{\frac{\psi}{1+\psi}}, \quad (36)$$

a function of deep parameters and individual tax rates.

With this equilibrium wage we can derive the level of individual outputs and prices. Rearranging the aggregation equation (30), we can write $w(t)\left(\frac{n^{\eta-1}C(t)}{Z(t)}\right)^{\frac{1}{\eta}} = \zeta(t) = \frac{(\theta-1)\eta}{\theta[1+\overline{\tau}(t)]}$, which implies that the real GDP path is

$$C^*(t) = nZ(t)\left(\frac{(\theta-1)\eta}{\theta n w(t)\,[1+\overline{\tau}(t)]}\right)^{\eta} \approx n^{1-\eta}Z(t)\left(\frac{(\theta-1)\eta}{\theta\mu\,[1+\overline{\tau}(t)]}\right)^{\frac{\eta}{1+\psi}}, \quad (37)$$

(where we used the approximation $1+\overline{\tau}(t) \approx 1+\widetilde{\tau}(t)$), which is again a function of model parameters and exogenous variables. The aggregate price level is the ratio of the nominal GDP (which is exogenous) and the real GDP:

$$P^*(t) = GDP(t)/C^*(t) \approx n^{\eta-1}\frac{1}{Z(t)}\left(\frac{\theta\mu\,[1+\overline{\tau}(t)]}{(\theta-1)\eta}\right)^{\frac{\eta}{1+\psi}}. \quad (38)$$

Then the expected growth rates can be calculated easily. From the wage equation (36), we have

$$E\left(g_w\right) = -\frac{\psi}{1+\psi}E\left(g_{1+\widetilde{\tau}}\right) \approx -\frac{\psi}{1+\psi}E\left(g_{1+\overline{\tau}}\right). \quad (39)$$

From the real GDP-equation (37), it follows that

$$E\left(g_Y\right) = E\left(g_C\right) \approx E\left(g_Z\right) - \frac{\eta}{1+\psi}E\left(g_{1+\overline{\tau}}\right). \quad (40)$$

Finally, from the price level equation (38), inflation is the difference between the nominal GDP-growth (g_{PY}, given exogeneously) and real GDP-growth:

$$E\left(\pi\right) = E\left(g_P\right) = g_{PY} - E\left(g_Y\right) = g_{PY} - E\left(g_Z\right) + \frac{\eta}{1+\psi}E\left(g_{1+\overline{\tau}}\right). \quad (41)$$

Observe that the pass-through of tax changes into inflation is influenced by two deep parameters in this model. Consider a tax increase. On the one hand, a lower η (returns to scale parameter in the production function) decreases the pass-through to inflation by decreasing the extent of fall in the growth rate of real GDP (and the nominal GDP growth is given exogeneously). On the other hand, a lower ψ (inverse of the labor supply elasticity) increases the pass-through through the following channel: higher labor supply elasticity leads to larger drop in equilibrium working hours and output, so the inflation effect will be higher (again assuming constant nominal GDP-growth).

Note also that in the absence of menu costs, there is no asymmetry in the pass-through after tax increases and decreases. Also, these equations imply that without tax changes, real GDP-growth and inflation are determined by the growth rate of the aggregate technology shock $Z(t)$.

2.6 Model solution with menu costs

The model with menu cost does not have a closed form solution, so we are going to solve it numerically. As the problem involves discrete choices resulting in kinks in the policy function, we are using value function iteration over a discretized state space for the solution.[11]

To obtain a transition matrix P_{aggr} over the aggregate state variables $(\pi_s, \zeta_s, g_Z, \tau^1, \tau^2, \phi)$ determining the probabilities of a state next period as a function of the current state, we are going to build a VAR system describing the firms' forecasts. The VAR is of the form:

$$\begin{pmatrix} \pi_s^f(t+1) \\ \log\zeta_s^f(t+1) \\ g_{Zs}(t+1) \\ \log\tau^1(t+1) \\ \log\tau^2(t+1) \\ \phi(t+1) \end{pmatrix} = A_0 + A_1 \cdot \begin{pmatrix} \pi_s(t) \\ \log\zeta_s(t) \\ g_{Zs}(t) \\ \log\tau^1(t) \\ \log\tau^2(t) \\ \phi(t) \end{pmatrix} + \Xi \cdot \begin{pmatrix} \epsilon_{\pi_s}(t+1) \\ \epsilon_{g_{Zs}}(t+1) \\ g_{\tau^1}(t+1) \\ g_{\tau^2}(t+1) \\ g_{\bar{\tau}}^+(t+1) \\ g_{\bar{\tau}}^-(t+1) \\ \Delta\phi(t+1) \end{pmatrix} \tag{42}$$

To obtain the parameters for this VAR system, the algorithm guesses inital parameters $(\gamma_1, \gamma_2, \gamma_3, \gamma_4\, \gamma_5, \gamma_6)$ of the inflation forecasting equation (24) using the flexible price solution. From this, it obtains a forecast for the $\zeta^f(t+1)$ using equation (26). Forecast for $g_{Zs}(t+1)$ is determined by equation (11) and the development of the tax rates (τ^1, τ^2) is simulated exogenously and from this $g_{\tau^1}, g_{\tau^2}, g_{\bar{\tau}}^+, g_{\bar{\tau}}^-$ are obtained. The transition matrix is obtained by simulating 5000 shocks for each element of the current aggregate state space and obtaining the percentages of getting into next period states. The transition matrix for the idiosyncratic technology level P_A was similarly obtained by the one variable method suggested by Tauchen (1986).

The initial guess for the value function is obtained using the flexible price equilibrium, and then it is iterated using the transition matrices P_{aggr}, P_A until convergence. From the value functions, we obtain the policy functions determining the states the firm is willing to change its price $P^{C/NC}$ and the level of new relative price in case of price change P^C. Using the policy functions, we simulate price developments of 2000 firms for 2000 periods. The

[11] In the baseline model, the state variables $(p_{si}, A_{si}, \pi_s, \zeta_s, g_{Zs}, \tau^1, \tau^2, \phi)$ have $(100, 29, 7, 7, 3, 2, 2, 2)$ grids respectively.

firms within a sector are partitioned between those facing τ^1 and τ^2 tax rates according to the sectoral CPI weights.

We obtain the aggregate state variables from this simulated sample. The model assumes that the firms know the current exogenous and endogenous state variables, including the current sectoral inflation rate π_s which is influenced by the current decisions of the firms. To model this, we are choosing the inflation rate every period as the grid-point which ensures that the guess of the firms for current inflation rate π_s^c and the resulting inflation rate π_s are the closest. The wage rate required to calculate the current sectoral cost factor ζ_s is obtained by equating the simulated labor demand to the simulated labor supply. Using these aggregate variables, we run an OLS regression of the forecasting equation (24) obtaining new estimates for γ. We are running the algorithm until the guessed and obtained parameters in the forecasting equation are sufficiently close to each other.

3 Data

We estimate the model and the effect of various value-added tax changes on a data set containing store-level price quotes. These data are originally used to the monthly calculation of the Consumer Price Index in Hungary.

The data set contains price quotes between December 2001 and December 2006, which enables us to observe the frequency and magnitude of price *changes* in 60 consecutive months. In terms of product categories, we have price information about 770 different representative items; the total CPI-weight of these items is 70.12% in 2006. The missing representative items are mainly regulated prices, or in some cases methodological problems make it impossible to collect data from different stores (e.g. used cars, computers).

After an initial data analysis, we dropped another 220 representative items, so finally we ended up with 550 representative items with a total CPI-weight of approximately 45.3%. Among these excluded items there are the fuels, alcoholic beverages and tobacco, where frequent changes in oil prices, and/or frequent indirect tax changes make it difficult to estimate the effect of value-added tax changes. Another reason of these exclusions was that for these representative items the maximum length of price spells were constrained. This could be because the Central Statistical Office began data collection about these products at a later date. (Examples are LCD TV-s, memory cards, MP3 players etc.) The other typical reason of exclusion was seasonal data collection: for some products (cherries, gloves, skis etc) the statistical office collects price quotes only in certain, pre-specified months of the year. All in all, this way we ensured that the maximum length of the observed price spells exceeds 36 months (3 years) for each representative item, which we regard long enough to get reliable estimates. The sample coverage (in 2006) by main CPI-categories is illustrated in Table 1[12].

These 550 representative items in the data set can be regarded as 550 mini panels, containing time series of price quotes from different outlets. As an example, consider item 10001 "Bony pork rib with tenderloin": the data set contains 7,922 observations from 162 different outlets, i.e. 48.9 price quotes per outlet. Moreover, for 96 of the 162 stores we have data for each month. As it is true for most of the representative items in the data set that the list

[12] The single 'Energy' item (propan-butan gas) remaining after the exclusions is included in the 'Other goods' category

Table 1: Coverage of the data set by CPI-categories

	CPI basket		Original sample		Final sample	
CPI category	**Weight**	**Items**	**Weight**	**Items**	**Weight**	**Items**
Food, alcohol, tobacco	31.842	222	31.322	220	20.272	162
Unprocessed food	5.665	53	5.665	53	4.151	34
Processed food	26.177	169	25.657	167	16.121	128
Proc. food excl. alc, tob	17.427	139	16.907	137	16.121	128
Clothing	5.305	171	5.305	171	3.147	101
Durable goods	9.240	112	4.976	73	3.562	49
Other goods	15.277	214	12.979	192	7.852	159
Energy	13.203	16	6.350	8	0.723	1
Services	25.134	161	14.679	106	9.789	78
TOTAL	**100.000**	**896**	**70.122**	**770**	**45.346**	**550**

Table 2: VAT rates in Hungary

VAT-rates in Hungary	Lower	Middle	Top
– Dec 31, 2003	0%	12%	25%
Jan 1, 2004 – Dec 31, 2005	5%	**15%**	25%
Jan 1, 2006 – Aug 31, 2006	5%	15%	**20%**
Sep 1, 2006 –	5%	**20%**	20%

of observed outlets is typically unchanged, the data is appropriate to investigate store-level developments in the prices, and also the pricing behavior of different stores.

On average, there are approximately 6,566 observations per representative item in the data set, which means that the total number of observations exceeds 3.6 million (3,611,335).

Our analysis will focus on regular prices, rather than sales prices. The price collectors of the Central Statistical Office use a sales flag to identify sales prices (i.e. prices that are temporarily low, and have a "sales" label), and we use these flags to filter out sales prices in the first round. After this we also filter out any remaining price changes that are (1) at least 10 %, (2) and are completely reversed within 2 months.

3.1 Inflation effects of VAT-changes

Individual products in Hungary are categorized into 3 distinct groups and face 3 distinct VAT tax rates. There are only a few products with extra subsidy (drugs, school books) facing the lowest tax rates. As these products only constitute 2.1% in CPI-weights of our sample, we will ignore these. The two other categories constitute the 46.8% and 51% of our sample. Table 2 presents the changes in the various tax rates. In January 2004 the middle rate was increased from 12% to 15%, and this same rate was increased again in September 2006 from 15% to 20%. The top rate, meanwhile was decreased in January 2006 from 25% to 20%. Ex post, the tax changes can be seen as a stepwise convergence of the middle and the top tax rates, though this outcome was not explicitly expressed ex ante by the fiscal authorities.

To estimate the inflation effect of these VAT-changes, Gabriel-Reiff (2007) decompose the inflation process into frequency and size effects. The starting point of this decomposition is the following identity: $\pi = fr^+\mu^+ - fr^-\mu^-$, where fr^+ and fr^- are frequencies of price increases and price decreases, and μ^+ and μ^- are average sizes of price increases and decreases (see Tables 2 and 3). Then VAT-changes influence the inflation rate through these four components.

Gabriel-Reiff (2007) estimate the effect of VAT-changes for all of these four components separately. To account for possible sectoral heterogeneities, they go to the sectoral level (representative items) and estimate the inflation effects of VAT-changes for each sector separately. Then they aggregate the sectoral inflation effects with the CPI-weights to obtain an overall inflation effect.

The main finding of Gabriel-Reiff (2007) is that VAT-increases and -decreases have very asymmetric effects on inflation (see Table 3). While the 2004 January VAT-increase (from 12% to 15%) and the 2006 September VAT-increase (from 15% to 20%) have increased the price level by 1.17% and 2.13%, respectively, after the 2006 January VAT-decrease (from 25% to 20%) the price level declined by only 0.92%. While some of these differences may be explained by the different sectoral decomposition of the affected items by the different VAT-changes, the differences still remain significant in those sectors when some items were affected by the VAT-increases, and some items were affected by the VAT-decrease (processed food and services).

Table 3: Inflation effects of VAT-changes

CPI category	**CPI weight**	**2004 Jan price effect**	**2006 Jan price effect**	**2006 Sep price effect**
Unprocessed food	4.151	2.12%	-0.54%	4.37%
Processed food	16.121	2.10%	-0.88%	3.30%
Clothing	3.147	0.17%	-1.22%	-0.03%
Durable goods	3.562	0.35%	-1.88%	0.46%
Other goods	8.575	0.45%	-1.25%	0.95%
Services	9.789	0.49%	-0.42%	1.58%
TOTAL	**45.346**	**1.17%**	**-0.92%**	**2.13%**

Gabriel-Reiff (2007) also investigate the main channel of price adjustment after the VAT-shocks. Their results indicate that adjustment mostly takes place through the "primary channel": after a VAT-increase, for example, adjustment is mainly driven by the stores' increasing willingness to increase prices, rather than by their decreasing willingness to decrease prices. Similarly, after a VAT-decrease most of the adjustment takes place through the outlets' increasing willingness to decrease prices.

Gabriel-Reiff also observe that the price of those products that are not directly affected by the VAT-changes may also change. They report that at the 2004 January and 2006 September VAT-increases the price level of non-affected items also increased by an average of 0.39% and 0.72%, and similarly, at the 2006 January VAT-decrease the price level of the non-affected items fell by 0.60%. In all cases, the biggest effect can be observed in those sectors where there are many close substitutes among the affected and non-affected products. (An example is cakes with and without chocolates in the processed food sector: cakes without chocolates were affected by the VAT-increases, while the cakes with chocolates were affected by the VAT-decrease.) This may hint that one should focus on relative rather than absolute tax rates when investigating price developments.

3.2 Data moments

We estimate model parameters by matching some data moments. This means that for an arbitrary combination of model parameters, we solve the model, simulate hypothetical data, calculate the moments, and compare them with the same moments estimated from data. We will obtain the estimated model parameters by matching these "theoretical moments" to the true "data moments".

At the heart of this procedure is the choice of moments, upon which the matching is based. Our choice is similar – though not identical – to the one by Klenow-Willis (2006), as we also use some extra moments to account for the tax changes:

- mean sectoral monthly inflation rate;
- (time-series) standard deviation of sectoral monthly inflation rate;
- frequency of price changes;
- average size of price changes;
- autocorrelation of new relative prices;
- inflation effect of value-added tax increases and decreases.

To describe the calculation of the *mean sectoral monthly inflation rate*, let us introduce some notation. We index time by t, representative items by s, and stores by i. Then the mean sectoral (i.e. representative item-level) inflation rate is

$$\pi_{st} = \sum_i \frac{\log P_{sit} - \log P_{si,t-1}}{N_i}, \tag{43}$$

where N_i is the number of stores observed both at time t and time $t-1$ in sector (representative item) s. From these we calculate average monthly inflation rates for the representative items by time aggregation:

$$\pi_s = \sum_t \frac{\pi_{st}}{T}, \tag{44}$$

and finally the mean monthly inflation rate for the whole economy (or broader CPI-categories) is obtained by aggregating over representative items:

$$\overline{\pi} = \sum_s w_s \pi_s, \tag{45}$$

where w_s are CPI-weights (we use the CPI-weights in 2006). Note that seasonal variation in monthly inflation rates does not affect our estimates as we are using price changes between January 2002 - December 2006 to calculate mean representative item-level inflation rates.

The time-series *standard deviation of sectoral monthly inflation rates* is calculated similarly. First we calculate the time-series standard deviation of π_{st} for each representative item:

$$\sigma_s^2 = \sum_t \frac{(\pi_{st} - \pi_s)^2}{T-1}, \tag{46}$$

and then calculate the weighted average of these across representative items:

$$\overline{\sigma} = \sum_s w_s \sigma_s. \tag{47}$$

As our theoretical model does not contain any seasonal variation, we calculate these measures on the seasonally adjusted π_{st} series (i.e. we subtract the estimated seasonal dummies).

The third moment that we use for matching is the *frequency of price changes*. These are again calculated at the representative item-level, and then aggregated across representative items:

$$\overline{I}_s = \sum_t \sum_i \frac{I(\Delta P_{sit} \neq 0)}{N_s}, \tag{48}$$

where $I(\Delta P_{sit} \neq 0)$ is a dummy for price changes, and N_s is the total number of observations for representative item s. The overall average frequency is then

$$\overline{I} = \sum_s w_s \overline{I}_s. \tag{49}$$

Again, seasonal variation in frequencies does not bias our frequency estimates as we use price change data between January 2002 - December 2006 for the frequency calculations.

The *average size of price changes* is calculated first at the representative item level:

$$\Delta P_s = \sum_{I(\Delta P_{sit} \neq 0)} \frac{|\Delta P_{sit}|}{N_{I_s}}, \tag{50}$$

where N_{I_s} is the total number of price changes for representative item s: $\sum_t \sum_i I(\Delta P_{sit} \neq 0)$. Then the average size across representative items is

$$\overline{\Delta P} = \sum_s w_s \Delta P_s. \tag{51}$$

Our fifth moment, the *autocorrelation of new relative prices* is taken from Klenow-Willis (2006) to calibrate the persistence of idiosyncratic shocks the hit the stores. To calculate this, we first obtain relative prices. Firm i's relative price in sector s is $p_{sit} = \log P_{sit} - \log \overline{P}_{st}$, where $\overline{P}_{st} = \sum_i P_{sit}/N_i$ is the average price at time t. We consider all relative prices that are newly set, and calculate the autocorrelation between these newly set relative prices at the store level:

$$\rho_{p,s,i} = \frac{\sum_{I(\Delta P_{sit} \neq 0)} (\log p_{sit} - \log \overline{p_{sit}})(\log p_{si,t-\tau_{sit}} - \log \overline{p_{sit}})}{\sum_{I(\Delta P_{sit} \neq 0)} (\log p_{sit} - \log \overline{p_{sit}})^2}, \tag{52}$$

where $\overline{p_{sit}}$ is the average of newly set relative prices, and τ_{sit} is the time (in months) between the previous and current price change. The autocorrelation at the representative item level is the average of $\rho_{p,s,i}$-s across stores: $\rho_{p,s} = \sum_i \rho_{p,s,i}/N_i$, while the overall autocorrelation of newly set relative prices is

$$\rho_p = \sum_s w_s \rho_{p,s}. \tag{53}$$

Finally, we also control for the *inflation effect of the value-added tax increases and decreases*. To be consistent with the model simulations, where we calculate these VAT-effects from time-series data, we also calculated these inflation effects from time-series data.[13] Specifically, we estimated the following time-series regression for each representative item:

$$\pi_{st} = \beta_0 + \sum_{k=1}^{11} \beta_k (MONTH = k)_t + \beta_{12} VAT04J_t + \beta_{13} VAT06J_t + \beta_{14} VAT06S_t + \varepsilon_t, \tag{54}$$

where the explanatory variables are month dummies, and other dummies corresponding to value-added tax changes. So the inflation effect of the various value-added tax changes are estimated by $\left(\widehat{\beta}_{12}, \widehat{\beta}_{13}, \widehat{\beta}_{14}\right)$, and the overall inflation effects are

$$\sum_s w_s \widehat{\beta}_{12,s}, \sum_s w_s \widehat{\beta}_{13,s}, \sum_s w_s \widehat{\beta}_{14,s}. \tag{55}$$

Klenow-Willis (2006) use another moment (*standard deviation of new relative prices*, σ_p) which we do not use. This is because we use the average size of price changes as a matching moment, which has similar information content with the standard deviation of new relative prices: they are both closely related to the variance of idiosyncratic technology shocks. Nevertheless, we will compare the value of σ_p in the model and in our data, to test the goodness of the estimates. Following Klenow-Willis (2006), we calculate σ_p similarly to ρ_p:

$$\sigma_{p,s,i} = \frac{\sum_{I(\Delta P_{sit} \neq 0)} \left(\log p_{sit} - \log \overline{p_{sit}}\right)^2}{\sum_t I\left(\Delta P_{sit} \neq 0\right)},$$

then at the representative item level $\sigma_{p,s} = \sum_i \sigma_{p,s,i}/N_i$, and at the aggregate level

$$\sigma_p = \sum_s w_s \sigma_{p,s}.$$

3.3 Stylized Facts

This section presents some qualitative statements obtained from observation of the data and its moments. The first couple of stylized facts are about the development of the moments during 'normal' times. It claims that the prices in terms of their major moments behave very similarly as was found in numerous studies using CPI data. It emphasizes the heterogeneity across sectors and shows that the price increases are more frequent, but on average smaller in size than the price decreases.

[13] The VAT effects calculated by Gabriel-Reiff, 2007 using panel estimations and the (averaged) time-series method we are using do not necessarily imply the same results, but as it can be seen by comparing Tables 3 and 4 they are sufficiently close to each other

The second part of the section presents the stylized facts about the development of major moments as a response to the tax changes. Other than emphasizing the asymmetry of inflation effects, the section shows that the fraction of the price changing firms clearly increased as a result of the tax shocks supporting 'state-dependent' pricing models, and is clearly smaller than 1 even in the subsample of directly affected products contrary to predictions of a frictionless, flexible price model. It also presents the result that the absolute magnitude of average price-changes decreases as a result of the tax shocks.

3.3.1 Stable frequency and large average absolute size of price changes.

Figure 2 and 3 show the fraction of firms changing prices and the magnitude of average price changes respectively in our sample. The average frequency of price change is fairly stable around the average (12%) level during 'normal' times in line with findings of previous studies (see e.g. Klenow and Krystov, 2007). Its relatively low level can be explained by the fact that some sectors with very flexible prices (e.g. fuel) were excluded from the sample (with these sectors the average frequency is 18.5%). The average absolute size of the price changes during 'normal' times – also in line with other studies – is high: it fluctuates around its average of 11.5%.

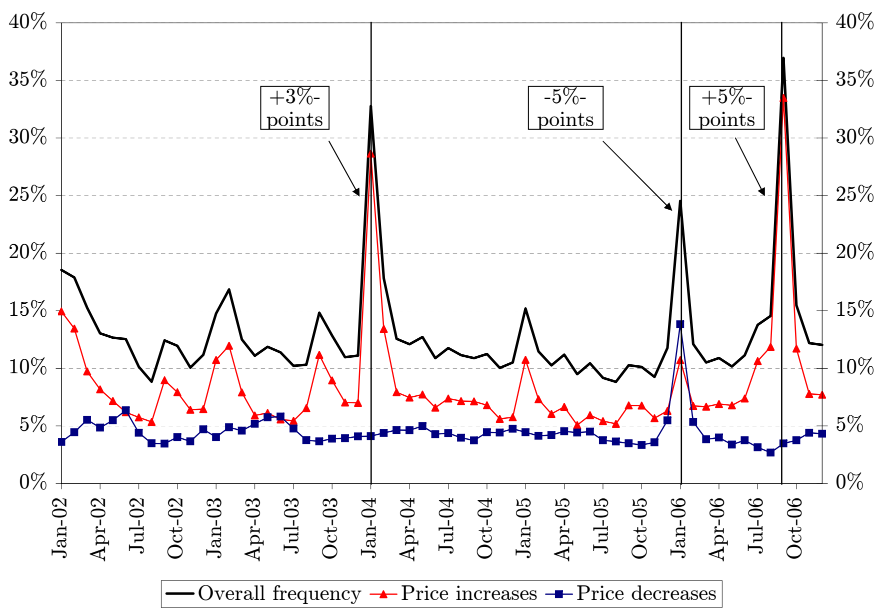

Figure 2: Frequency of price changes

3.3.2 Price increases are more frequent, but smaller than price decreases

Figures 2 and 3 also present the fraction of price increasing and price decreasing firms as well as the average absolute size of price increases and decreases. They show that the fraction

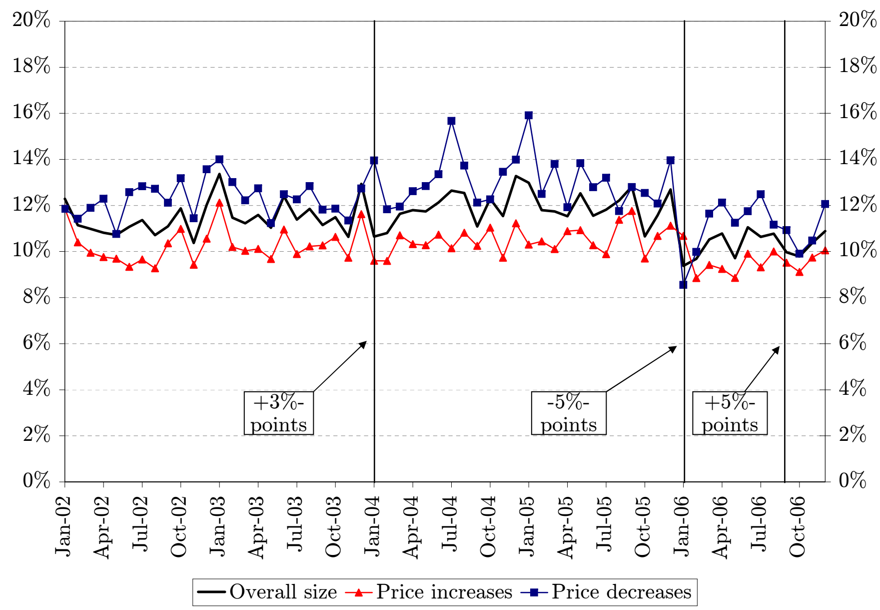

Figure 3: Average absolute size of price changes

of price increasing firms are consistently higher (7.7% on average) than the fraction of price decreasing firms (4.3%). As a mirror image of this fact, the average absolute size of price increases are consistently lower (10.2%) than those of the price decreases (12.4%).

3.3.3 There is a large sectoral heterogeneity

Table 4 reports the calculated moments for the main CPI-categories for each examined sectors, with frequency and sizes calculated for 'normal' non-tax change months and tax change months as well. We can interpret these figures as moments calculated from a "typical" representative item in the respective CPI-categories. The model parameters are about to be calibrated to for each CPI-category to match these typical representative items.

Table 4: Estimated data moments

CPI category	$\overline{\pi}$	$\overline{\sigma}$	$\overline{I}_{NT}$	$\overline{I}_T$	$\overline{\Delta P}_{NT}$	$\overline{\Delta P}_T$	ρ_p
Proc. food	0.429%	0.91%	0.134	0.529	0.099	0.088	0.010
Unproc. food	0.282%	2.64%	0.322	0.640	0.116	0.111	0.230
Clothing	-0.119%	0.63%	0.065	0.089	0.157	0.137	-0.123
Durable goods	-0.260%	0.51%	0.088	0.130	0.100	0.093	-0.100
Other goods	0.125%	0.62%	0.094	0.2	0.110	0.105	-0.076
Services	0.699%	0.67%	0.063	0.252	0.138	0.111	-0.031
All	**0.324%**	**0.91%**	**0.120**	**0.356**	**0.115**	**0.102**	**-0.013**

Table 4 shows that both in terms of the sectoral inflation rates and price rigidities the sectors show sizable heterogeneity. The two largest sectors affected by all of the tax changes (the processed food and the services sectors) are also different: the services sector facing higher inflation rate and higher price rigidity than the processed food sector.

3.3.4 The inflation effects are asymmetric

Table 5 presents the estimated VAT effects for each sectors. As the relative weights of products facing the middle and top tax rates are different across sectors (see the columns 'middle' and 'top'), the overall inflation effects calculated from the regressions 54 are not directly comparable. We can, however, compute the inflation effect of a unit tax increase which is directly comparable (presented in the last three columns of Table 5) and calculated by dividing the overall effect by change in the average sectoral tax rate. Comparing the effects of the 2006 January 5% tax decrease and the 2006 September 5% tax increase shows the magnitude of the asymmetry this paper is about to explain.

Table 5: Estimated VAT effects

CPI category	**CPI weights**		**Overall**			**Unit**		
	middle	top	VAT04j	VAT06j	VAT06s	VAT04j	VAT06j	VAT06s
Proc. food	78.8%	21.2%	1.660	-0.770	3.471	0.810	0.839	1.044
Unproc. food	100%	0%	1.150	-0.137	4.724	0.435	NA	1.11
Clothing	1%	99%	0.211	-1.085	0.212	NA	0.268	NA
Durable goods	0%	100%	0.118	-1.661	0.602	NA	0.407	NA
Other goods	17.8%	82.1%	0.436	-1.032	0.881	0.986	0.303	1.203
Services	32.1%	67.9%	0.495	-0.848	1.413	0.615	0.299	1.06
All	**47.9%**	**52.1%**	**0.909**	**-0.870**	**2.200**	**0.748**	**0.395**	**1.104**

3.3.5 Frequency increases, size decreases during VAT shocks

The fraction of firms changing prices clearly increases (31.4% from 13%) in the months of the tax changes, as it can be seen in Figure 2, in line with international evidence (see Gagnon, 2007 and the references there.) It should be noted, however, that the frequency of price changing firms is strictly less than 1 even in the subsamples of directly affected firms (around 60%) providing some evidence against fully flexible price setting.

The average size of price changes during the months of tax changes decreases (from 11.5% to 10.2%) as it can be seen in Figure 3. The systematic nature of this outcome is underlined by the fact that it is also true in all of the sectors, as Table 4 shows.

4 Calibration Results

The parameters are set to hit some important moments of the data, and our main interest is whether the model is able to explain the (asymmetric) response of the inflation rate to the tax changes. We going to present 3 estimates: the first ignores sectoral heterogeneity and estimates the model on the aggregate data, while the other 2 estimates the model on the processed food and the services sectors. These two sectors are the largest in our sample – 16.1% and 9.8% overall CPI weights – including products facing both tax rates. Our estimations imply that the major difference between the sectors is the level of their trend inflation rate and it is the main reason for their different responses to the tax shocks: while the asymmetry between a unit tax increase and tax decrease in the processed food sector is only marginally significant, the services sector shows significantly higher inflation effect of a unit tax increase.

4.1 Parametrization

We calibrate the model parameters by fitting simulated moments to some of the observed sectoral characteristics of the data. Some of the parameters are fixed exogenously. We calibrate $\beta = 0.96^{1/12}$, and the mean aggregate nominal growth rate to $g_{PY} = 0.0934 \cdot (1/12)$, which is the average monthly growth in Hungary over the period 2002:01-2006:12. The persistence of the aggregate technology shock is set to $\rho_{gz} = 0.7$.

We set the value of θ determining the level of competition within a sector to 11, which is a usual number used in the macro literature implying a 10% markup. Choosing a relatively high value for this variable (in the industrial organization literature a $\theta \approx 4$ is more common) is also justified by the fact that Devereux and Siu, 2007 predicts stronger strategic asymmetry in case of high θ. The choice of θ determines the asymmetry of the profit and the value functions, thereby influences the relative frequency and the size of the price increases and decreases. The fact that model is fairly successful in hitting these moments provides support for the chosen magnitude of θ.

In this version of the paper, we set $\eta = 1$ implying constant returns to scale. Examining the case with $\eta < 1$ is an interesting avenue for further research, as it would imply steeper and more convex cost function making the firms more sensitive to the demand effects, so we can expect the strategic consideration based on demand effects to be stronger.

The other parameters of the model are calibrated to match some important sectoral pricing characteristics. The mean of the sectoral technology growth μ_{gz} is calibrated to make the simulated inflation rate equal to the mean sectoral inflation $\bar{\pi}$. Other parameters do not have a clear one-to-one relationship between one moments, but we have good idea how they influence the moments we would like to hit. The standard deviation of the sectoral technology growth σ_{gz} increases the estimated average standard deviation of the inflation rate $\sigma_{\bar{\pi}}$, the frequency and marginally the size of the price changes. The persistence of the (logarithm of the) idiosyncratic technology shock ρ_A increases the persistence of the relative price developments ρ_p and its standard deviation σ_A increases the frequency, the size of the price changes and the standard deviation of the relative prices σ_p. The menu costs ϕ decreases the frequency and increases the size of the price changes. The labor supply elasticity $1/\psi$ influences the inflation effects of the tax changes, as it influences how much of its effect is buffered by the relative wage and thereby the cost adjustment. Higher labor supply elasticity (lower ψ) implies lower wage response, thereby higher inflation effects of the tax change. The labor-utility parameter μ is calibrated in each sector to set the aggregate labor supply equal to 1/3.

So to sum up, we have 8 'moving' parameters $(\mu_{gZ}, \sigma_{gZ}, \rho_A, \sigma_A, \phi_{NT}, \phi_T, \psi, \mu)$ and we use them to hit 8 major moments (we call them 'matched moments') of the data $(\bar{\pi}, \sigma_{\bar{\pi}}, \rho_p, \bar{I}_{NT}, \bar{I}_T, \Delta P_{NT}, \bar{L}, \bar{\pi}_T)$, where the subscripts NT and T refer to averages during 'normal' times and tax shocks respectively, $\bar{L}$ is the sectoral labor supply (equal to the third of the sector CPI-share), and the $\bar{\pi}_T$ is the average inflation effects of the tax changes. Other moments of the data can be used to evaluate the performance of the model (we call them 'unmatched moments'), and these are the effects of the positive and negative unit tax changes ($\gamma^{\pm}$), the standard deviation of the relative prices σ_p, the average size of price changes during the months of the tax changes ΔP_T, and the frequency and the size of price increases and decreases ($\bar{I}^{\pm}, \Delta P^{\pm}$).

4.2 Results

Table 6 presents the parameters for each calibrations (aggregate, processed food and services) and the estimated forecasting equations with the resulting goodness of fit parameters. Table 7 presents the values of the moments which were directly used for the calibration ('matched moments') and the values of the 'unmatched' moments.

The forecasting equations show that the estimated parameters of the state variables in equation (24) are in most cases significant and are able to explain 50%, 78% and 60% of the variance of the inflation rate in the aggregate, processed food and services sector calibrations respectively. These results imply that using higher order moments might be justified for the forecasting equation. It should be noted however, that as we assume that firms know the current value of inflation rate when choosing current prices, the forecasting equation can be expected to have only limited effects on their decision, so adding new variables and obtaining better fit can be expected to have limited effect on our results.

4.2.1 The model is successful at hitting major moments during 'normal' times

The results show that the model is fairly good at hitting most of the moments representing 'normal times' for both the aggregate and the sectoral calibrations.

Looking at the aggregate calibration, the overall frequency of price change during 'normal times' is 12.0% and the size of the price changes is 11.5% which are somewhat different from those found in the CPI data in other countries [14] showing that our sample overrepresents sectors with less price flexibility (we have excluded energy, alcohol and tobacco for example). Similarly to previous menu cost models with idiosyncratic shocks, the model needs idiosyncratic shocks with large unconditional standard deviation ($\sigma_A^u = \frac{\sigma_A}{\sqrt{1-\rho_A 2}} = 6.5\%$) to be able to hit the large average size and frequency of the price changes.

The menu cost in case of no tax change is estimated to be 5.5% when paid, but note that it is only paid in case of price change which – under no tax change – happens with 12% probability. It means that the yearly menu cost proportional to the firms' revenue is estimated to be 0.66%, which is within the range of estimated menu cost levels in previous studies (Klenow-Willis, 2006 estimates a yearly cost of 1.4%, while Nakamura-Steinsson, 2007 finds this measure to be 0.2%).

The sectoral estimations can also be considered successful at hitting the major moments. The major difference between the two sectors is that the services sector faces both higher yearly trend inflation (8.7% compared to 4.9%) and higher estimated menu costs (11% compared to 3.8%[15]) than the processed food sector. These differences can fully explain both

[14] Nakamura and Steinsson, 2007, for example, reports median frequency of 21.1% and size at 8.5% for the US data

[15] Implying reasonable 0.69% and 0.5% yearly menu costs

Table 6: Calibrations

	Parameters	Aggr.	Food	Services
σ_{g_Z}	Std. dev. of sectoral technology growth	10%	6%	1.3%
ρ_A	AR. parameter of the idiosyncratic shocks	0.600	0.675	0.35
σ_A	Std. dev. of idiosyncratic shocks	5.2%	4.5%	6%
ϕ_{NT}	Menu costs during 'normal' times	5.5%	3.8%	11%
ϕ_T	Menu costs during tax changes	2.7%	1.4%	4.1%
ψ	Inverse of the Frisch elasticity of labor supply	1	0	0.1
μ	Utility weight of the labor supply	7	6.75	13
	Forecast of $\pi_s(t+1)$ as a function of	**Aggr.**	**Food**	**Services**
γ_1	Constant	0.014	0.008	0.013
		(0.001)	(0.001)	(0.002)
γ_2	Current inflation $\pi_s(t)$	0.017	0.031	0.014
		(0.022)	(0.012)	(0.015)
γ_3	Cost parameter $\xi_s(t)$	0.033	0.007	0.025
		(0.005)	(0.006)	(0.006)
γ_4	Technology growth $g_{Zs}(t)$	-.615	-.692	-.544
		(0.029)	(0.024)	(0.09)
γ_5	Positive average tax growth $g_{\bar{\tau}}^{+}(t+1)$	0.533	0.882	0.882
		(0.032)	(0.002)	(0.019)
γ_6	Negative average tax growth $g_{\bar{\tau}}^{-}(t+1)$	0.622	0.820	0.367
		(0.034)	(0.02)	(0.02)
R^2	Goodness of fit	50%	78%	60%

the substantially lower fraction of price changing firms in the services sector (6.3% compared to 13.3%) and the substantially higher average absolute size of price changes in the services sector (13.8% compared to 9.9%) than in the processed food sector. The calibrations imply fairly similar unconditional idiosyncratic standard errors (σ_A^u being 6.4% and 6.1% in the services and processed food sectors respectively).

The variance of the relative prices σ_p is the moment which is significantly missed in all calibrations. It seems to be a systematic weakness of the model appearing in all the presented estimation: when the model is parameterized to hit the average size of price changes, it underestimates the relative price variation. The model, on the other hand, is fairly successful at quantitatively hitting the frequencies and the sizes of price increases and price decreases. It suggests that the level of asymmetry in the profit and value function inherent in the standard CES framework, and the chosen relatively high elasticity of substitution parameter ($\theta = 11$) is a valid choice.

Table 7: Moments

	Matched Moments		**Aggr.**	**Food**	**Services**
$\bar{\pi}$	Average inflation rate	Data	0.3%	0.4%	0.7%
		Estimate	0.3%	0.4%	0.7%
$\sigma_{\bar{\pi}}$	Std. dev. of inflation rate	Data	0.9%	0.9%	0.7%
		Estimate	0.9%	0.9%	0.7%
ρ_p	Autocorrelation of new relative prices	Data	-0.013	0.01	-0.031
		Estimate	-0.028	0.07	0.033
$\bar{I}_{NT}$	Frequency during 'normal' times	Data	12%	13.3%	6.3%
		Estimate	12%	13.3%	6.3%
$\bar{I}_T$	Frequency during tax changes	Data	31.4%	40.5%	26.1%
		Estimate	30%	40.2%	26.1%
ΔP_{NT}	Size during 'normal' times	Data	11.4%	9.9%	13.8%
		Estimate	11.5%	9.9%	13.3%
	Unmatched Moments		**Aggr.**	**Food**	**Services**
γ^+	Inflation effect of a unit tax increase	Data	1.104	1.044	1.064
		Estimate	0.632	0.927	0.996
γ^-	Inflation effect of a unit tax decrease	Data	0.394	0.839	0.300
		Estimate	0.716	0.581	0.439
σ_p	Std. dev. of relative prices	Data	11.4%	9.4%	12.3%
		Estimate	7.4%	6.6%	7.0%
ΔP_T	Size during tax changes	Data	10%	9.0%	11.1%
		Estimate	10%	8.2%	10.9%
$\bar{I}^+$	Frequency of price increases	Data	7.7%	8.9%	5.6%
	during 'normal' times	Estimate	7.96%	8.9%	5.4%
$\bar{I}^-$	Frequency of price decreases	Data	4.3%	4.5%	0.7%
	during 'normal' times	Estimate	4.1%	4.5%	0.9%
ΔP^+	Size of price increases	Data	10.2%	9.3%	13.5%
	during 'normal' times	Estimate	10.6%	9.3%	12.9%
ΔP^-	Size of price decreases	Data	12.4%	10.5%	14.5%
	during 'normal' times	Estimate	12.4%	10.5%	13.9%

4.2.2 The model implies lower menu costs during VAT shocks

Maintaining homogeneous menu costs does not seem to be unable to quantitatively match the larger frequency and lower size of price changes during VAT shocks. As the major question of the paper is the asymmetry of the inflation effects, in this version of the paper, we allowed, as a shortcut, the menu cost to be lower during tax changes. This assumption allowed us to hit both the frequency and the size of price changes, and the fact that setting the menu cost to hit the frequency of price changes during tax changes ($\bar{I}_T$) is able to hit the average absolute size of price changes ΔP_T as shown in Table 7 provides some support for our choice of heterogeneous menu costs.

For the aggregate estimations the menu cost (when paid) is estimated to be 2.7% (from 5.5%), while for the sectoral estimations it is 1.4% (from 3.8%) for the processed food sector and 4.1% (from 11%) for the services sector. The size of the reductions can be given more justifications by noting that, as Zbaracki et. al., 2004 found, the information-gathering and decision-making costs related to price changes – which can be considered lower in case of the tax changes – can be an order of magnitude larger (around 1.2%) than the physical costs of price changes (0.05%) – which are the same in both cases.

4.2.3 The aggregate model misses, the sectoral model fully explains the level of asymmetry

Although both the aggregate and the sectoral calibrations hit most of the moments, the aggregate model significantly underestimates the observed asymmetry: it predicts a response with (marginally) reverse asymmetry to a unit tax shock (0.632 and 0.716 respectively), while the data shows much stronger response (1.104) to a tax increase than to the tax decrease (0.395). A possible reason for this is that the non-sectoral model does not take the sectoral heterogeneity into consideration. Among other things, it ignores the sectoral inflation differences which cause different sectoral asymmetric effects. If the inflation effect on the asymmetry is not linear, the non-sectoral model can be expected to underestimate the asymmetry. This argument justifies the sectoral calibration of the model.

The sectoral calibrations are much more successful in hitting the asymmetric inflation effects of the tax changes. In line with the qualitative predictions of the model, the asymmetry is much more substantial in the services sector, which is the sector with the higher inflation rate and lower price flexibility. The model is also successful quantitatively. In the processed food sector the inflation effects of unit tax increases are estimated to be 1.04 and 0.84 respectively. The model underestimates the inflation effects of the tax shocks (even with fully flexible labor supply with $\psi = 0$)[16], and somewhat overestimates the asymmetry by predicting coefficients with 0.93 and 0.58 respectively. In the services sector, the coefficients of the unit tax changes are 1.06 and 0.299 respectively, and the model is very successful in hitting these parameters by predicting 0.996 and 0.439 as coefficients for the tax increase and decrease respectively.

[16] A possible reason for this is that the firms might have considered the tax changes more persistent ex ante than in our current simulations based on the ex post tax changing frequencies.

4.2.4 Inflation is the major reason of the sectoral asymmetry

For our parametrization, the sole economically significant reason of the observed sectoral asymmetry is the trend inflation. Devereux and Siu, 2007 suggested that in a model similar to ours strategic considerations should result in quantitatively important asymmetries. Running a counterfactual experiment resulting in 0 average inflation rate, we have found no significant asymmetry in any of the sectors. These results suggest that even with fairly high level of competition ($\theta = 11$), the 5%-points tax changes were not large enough to induce strategic asymmetry.

It should be noted, though, that in this version of the paper, we assumed constant returns to scale $\eta = 1$, and the steeper and more convex cost function implied by decreasing returns to scale could increase the effects of this asymmetry, by making the firms' profits more sensitive to the demand they face. We are planning to examine this effect in later versions of the paper.

5 Conclusion

The paper presented a sectoral menu cost model calibrated to fit some key moments of the sectoral price development in Hungary between 2002-2006 in order to explain the observed asymmetric inflation response to major VAT changes. The paper argued that the successful calibration needed deviations from the homogeneous menu cost framework on the one hand, and sectoral calibrations, on the other. The paper found that (sectoral) trend inflation can fully account for the observed asymmetry, thereby it provided direct evidence to the argument of Ball and Mankiw, 1994.

The present model can be used to examine the asymmetry of the monetary policy shocks by simulating positive and negative nominal GDP level and growth shocks. By straightforward extensions, furthermore, it can be made able to examine the non-linearity of the inflation effects using the 2004 January 3% point increase of the 12% VAT tax rate. The dynamic response of inflation to the VAT shocks seems very different from a standard prolonged and hump shaped response to monetary shocks found in structural VAT estimations, which can be a further interesting question for future research.

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