Asymmetries in Price Developments: Some Micro Data Evidence

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Abstract

The paper calibrates a standard sectoral menu cost model on a new micro-level CPI data set of Hungary to explain the observed asymmetries in price developments as a response to value-added tax (VAT) changes. The model is able to reproduce important moments of the data, and finds that the major part of the asymmetry is explained by the presence of sectoral trend inflation as was argued by Ball and Mankiw, 1994. It finds little evidence that strategic asymmetries emphasized recently by Devereux and Siu, 2007 have significant effects on the results.

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JEL Classification: E30

1 Introduction

Fiscal authorities in Hungary have provided an interesting natural experiment by engineering two major value added tax increases and a major tax decrease within 32 months. These VAT shocks can provide valuable information about the pricing behavior of firms[1], as these exogenous cost push shocks influence a large number of firms simultaneously in an easily measurable way.

Panel analysis of the data (Gabriel-Reiff, 2007) found that, in line with previous empirical research using aggregate data (see e.g. Cover, 1992, Peltzman, 2000, Ravn and Sola, 2004), the shocks had asymmetric aggregate inflation effect. According to the estimates, while the 2004 January 3%-points increase of the 12% VAT rate and the 2006 Septermer 5%-points increase of the 15% VAT rate – both influencing the same 46.9% of the products in our sample – increased the CPI in the sample by 1.17% and 2.13%, respectively, the 2006 January 5%-points decrease of the 25% VAT rate – influencing another 51.0% – decreased the CPI only by 0.92%. The asymmetry is even more pronounced in the subsamples of products directly

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

affected by the tax changes: their average price increase was 2.05% for the VAT increase and only -1.24% for the VAT decrease.

Menu cost models, which assume that firms face a small fixed cost in case they choose to change their prices, provide interesting arguments for explaining asymmetric inflation responses to aggregate marginal cost shocks. Ball and Mankiw, 1994, argues that positive trend inflation rate (π) causes asymmetry, because the inflation automatically drives the firms' desired price ($P^* = \pi + \epsilon$) away from their current price, so for any given symmetric menu cost, the firm is going to be willing to increase its price for smaller positive (monetary) shocks ϵ, and it needs larger shocks to decrease it. Devereux and Siu, 2007 provide a different argument 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. Their result is based on the asymmetric effects of price adjustments on the individual demand in case of positive and negative shocks. Consider a positive marginal cost shock: if a firm does not increase its own price as a response of others increasing theirs, its demand is going to be high, so its suboptimal price will cause it relatively high losses. However, in case of a negative marginal cost shock, if the others have already decreased their prices, it faces low demand, so it has less incentives to decrease its price with the others.

The different sectoral composition of the observed tax changes can provide further, more case specific reason for asymmetric inflation effects. The VAT increases and the decrease affected various sectors differently, the VAT increase causing more inflation effect hitting disproportionally the sectors with more flexible prices, providing some explanation for the observed asymmetry which needs to be controlled for.

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. [2]

This paper quantifies the effects of the various sources of the asymmetry by applying a CES utility version of Klenow-Willis, 2006 sectoral menu cost model with sizeable idiosyncratic shocks and value-added tax. The model assumes that the firms determine correct linear beliefs about the development of the endogenous state variables as is assumed in Krusell and Smith, 1998, and solves the model numerically by value function iteration. This model incorporates positive inflation rate as in Ball and Mankiw, 1994, as well as asymmetric profit and value functions as in Devereux and Siu, 2007, so is able to compare the numerical influence of the two effects. The sectoral estimation allows the method to control for sectoral heterogeneity.

[2] 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.

2 The Model

The paper uses a version of Klenow and Willis, 2006 sectoral menu cost model with standard monopolistic competition, CES preferences and value added tax rates.[3]

2.1 The consumer

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

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

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 $L_s, s=1,\ldots,S$ according to his utility.

The consumer's periodic budget constraint is given by

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

where $P_{si}(t)$ is the gross price, $B(t)$ is a state dependent nominal asset (nominal Arrow-security) with state dependent gross return $R(t)$, $T(t)$ 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

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

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

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

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

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

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

2.2 The government

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 random walk

$$\log(1 + \tau_s^j(t+1)) = \log(1 + \tau_s^j(t)) + \epsilon_{\tau_s^j},\ \ \epsilon_{\tau_s^j} \sim N(0, \sigma_{\tau_s}^2). \tag{7}$$

The assumption implies that the expected level of the tax rate next period is the current tax rate, though there is some uncertainty about its development. The government is assumed to maintain a balanced budget every period[4]:

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

2.3 The firms

The firms' problem is to maximize the present value of their profits in a menu cost environment. In line with previous studies, we assume firms are facing small fixed physical, information-collecting and decision making costs in case they change their nominal prices. We denote this cost $\tilde{\phi}(t) = \phi(t)\frac{P(t)Y(t)}{n}$, and assume that it is proportional to their revenue. We assume that in case of tax shocks, these menu costs are smaller than in case of more general shocks. By this assumption, our model is able to reproduce the stilized fact showing that the average frequency is larger and the average size of price change is lower in case of a tax shock than for other shocks.[5] Our reasoning is that tax shocks are widely publicized easily measurable cost shocks which have considerable effects on the costs of the individual firms, so it can be expected to require less information collecting and decision making costs than in case of more complicated cost shocks.

In each sector, we distinguish two groups 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 that the tax changes influenced only part of the firms in each sector, and try to capture some of the characteristics of the spillover of the tax changes observed in the data.

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

$$Y_{si}^j(t) = Z_s(t) A_{si}(t) L_{si}^j(t)^\eta. \tag{9}$$

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

$$g_{Zs}(t+1) - \mu_{g_{Zs}} = \rho_{g_{Zs}} \left(g_{Zs}(t) - \mu_{g_{Zs}}\right) + \epsilon_{g_Z s}(t+1), \tag{10}$$

[4]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 $\tau P^n C = \frac{\tau}{1+\tau} PC$.

[5]Assuming multi-product firms suggested by Midrigan, 2007 can also be expected to explain this stilized fact in a more complicated and computationally more challenging way.

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

$$\log A_{si}(t+1) = \rho_{A_s} \log A_{si}(t) + \epsilon_{A_{si}}(t+1), \tag{11}$$

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

This production function (9) implies an individual labor demand

$$L^j_{si}(t) = \left(\frac{Y^j_{si}(t)}{Z_s(t) A_{si}(t)} \right)^{\frac{1}{\eta}}, \tag{12}$$

which aggregates to a sectoral labor demand given by

$$L_s(t) = \sum_{i=1}^{n_s^1} L^1_{si}(t) + \sum_{i=n_s^1+1}^{n_s} L^2_{si}(t). \tag{13}$$

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

$$\max E \sum_{t=0}^{\infty} \frac{1}{\prod_{q=0}^{t} R(q)} \tilde{\Pi}^j_{si}(t), \tag{14}$$

where the periodic profit level is given by

$$\tilde{\Pi}^j_{si}(t) = \frac{1}{1+\tau^j_s(t)} P^j_{si}(t) Y^j_{si}(t) - \tilde{w}(t) \left(\frac{Y^j_{si}(t)}{Z_s(t) A_{si}(t)} \right)^{\frac{1}{\eta}}. \tag{15}$$

Using the fact that in equilibrium the demand $Y^j_{si} = C^j_{si}$, equation (4) implies

$$\tilde{\Pi}^j_{si}(t) = \frac{1}{1+\tau^j_s(t)} \frac{1}{n_s} P^j_{si}(t) \left(\frac{P^j_{si}(t)}{P_s(t)} \right)^{-\theta_s} Y_s(t) - \tilde{w}(t) \left(\frac{\frac{1}{n_s} \left(\frac{P^j_{si}(t)}{P_s(t)} \right)^{-\theta_s} Y_s(t)}{Z_s(t) A_{si}(t)} \right)^{\frac{1}{\eta}}. \tag{16}$$

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

$$\Pi^j_{si}(t) = \frac{\tilde{\Pi}^j_{si}(t) n_s}{\alpha_s P(t) Y(t)}, \tag{17}$$

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

$$\Pi^j_{si}(p^j_i(t), A_i(t), \zeta(t), \tau^j(t)) = \frac{1}{1+\tau^j_s(t)} \left(p^j_{si} \right)^{1-\theta_s} - \left(p^j_{si}(t) \right)^{-\frac{\theta_s}{\eta}} w(t) \zeta_s(t) A_{si}(t)^{-\frac{1}{\eta}} - \phi(t). \tag{18}$$

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

$$V^j\left(p^j_{is,-1}, \Omega_{si}\right) = \max_{\{C,NC\}}\left(V^{NC,j}\left(p^j_{is,-1}, \Omega_{is}\right), V^{C,j}\left(p^j_{is,-1}, \Omega_{is}\right)\right), \tag{19}$$

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

$$V^{NC,j}\left(p^j_{is,-1}, \Omega_{is}\right) = \Pi^j_{si}\left(\frac{p^j_{si,-1}}{1+\pi_s}, A_{si}, \zeta_s, \tau^j_s\right) + E\frac{1}{R}V\left(\frac{p_{si,-1}}{1+\pi_s}, \Omega'_{si}\right) \tag{20}$$

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

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

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 $g_{Zs}(t+1), \tau^1(t+1), \tau^2(t+1), \phi(t+1)$:

$$\Gamma_s(t+1) = \Theta(\Gamma_s(t), \Lambda_s(t+1), g_{Zs(t+1)}, \tau^1(t+1), \tau^2(t+1), \phi(t+1)) \tag{22}$$

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 (19), (20), (21) knowing the current values of the state variables and correctly predicting the development of the idiosyncratic shock (11), the sectoral technology shock (**??**), the taxes (7) 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 (22) predict only the inflation rate – the aggregate moment they are interested in – using a linear equation:

$$\pi^f_s(t+1) = \gamma_1 + \gamma_2\pi_s(t) + \gamma_3\zeta_s(t) + \gamma_4 g_Z(t) + \\ \gamma_5 g^+_{\tau}(t+1) + \gamma_6 g^-_{\tau}(t+1) + \epsilon_\pi,\ \epsilon_\pi \sim N(0, \sigma_{\epsilon_\pi}) \tag{23}$$

containing all the current sectoral state variables. The equation also contains the next period increase/decrease of the average tax rates $g_{\tau}^{\pm}$. 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

$$g_{Y_s}^f(t) = g_{PY} - \pi_s^f(t), \tag{24}$$

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

$$\log \zeta_s^f(t) = \log \zeta_s(t-1) + \frac{1}{\eta} g_{Y_s}^f(t) - \frac{1}{\eta} g_{Z_s}(t) + g_w^f(t), \quad g_w^f = \frac{\psi}{\eta}\left(g_Y^f(t) - g_Z(t)\right). \tag{25}$$

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 (12) and the labor supply equation (6).

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

$$\log(P(t+1)Y(t+1)) = \log(P(t)Y(t)) + g_{PY}, \tag{26}$$

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.[6]

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

$$p_i^*(t) = \left(\frac{\theta w(t)\widehat{\zeta}(t)}{\theta - 1}\frac{1+\tau_i(t)}{\eta A_i(t)^{1/\eta}}\right)^{\frac{\eta}{\theta+\eta-\theta\eta}}, \tag{27}$$

with $\widehat{\zeta}(t) = \left(\frac{C(t)}{nZ(t)}\right)^{\frac{1}{\eta}}$, and $w(t) = \frac{\tilde{w}(t)}{P(t)C(t)/n}$ being the nominal wage normalized by the average nominal revenue of the firms.

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

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

$$C_i^*\,(t) = \left(\frac{C(t)}{n}\right)^{\frac{\eta-\theta\eta}{\theta+\eta-\theta\eta}} Z(t)^{\frac{\theta}{\theta+\eta-\theta\eta}} \left(\frac{\theta w(t)}{(\theta-1)\eta}\right)^{\frac{-\theta\eta}{\theta+\eta-\theta\eta}} \left(\frac{1+\tau_i(t)}{A_i(t)^{1/\eta}}\right)^{\frac{-\theta\eta}{\theta+\eta-\theta\eta}}. \qquad (28)$$

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

$$\frac{(\theta-1)\,\eta}{\theta\widehat{\zeta}(t)w(t)} = \left[\sum_i n^{-1}\left(\frac{1+\tau_i(t)}{A_i(t)^{1/\eta}}\right)^{\frac{\eta-\theta\eta}{\theta+\eta-\theta\eta}}\right]^{\frac{\theta+\eta-\theta\eta}{\eta-\theta\eta}} \equiv 1+\overline{\tau}(t), \qquad (29)$$

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

$$p_i^*(t) = \left[\frac{(1+\tau_i(t))\,/A_i(t)^{1/\eta}}{1+\overline{\tau}(t)}\right]^{\frac{\eta}{\theta+\eta-\theta\eta}}, \qquad (30)$$

and relative outputs as

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

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:

$$L(t) = \left(\frac{\widetilde{w}(t)}{\mu P(t)C(t)}\right)^{\frac{1}{\psi}} = \left(\frac{w(t)}{n\mu}\right)^{\frac{1}{\psi}}, \qquad (32)$$

while labor demand is formed by firms:

$$L_i(t) = \left(\frac{C_i^*(t)}{Z(t)A_i(t)}\right)^{\frac{1}{\eta}} = \frac{(\theta-1)\,\eta}{\theta w(t)\,[1+\overline{\tau}(t)]\,A_i(t)^{1/\eta}} \left[\frac{(1+\tau_i(t))\,/A_i(t)^{1/\eta}}{1+\overline{\tau}(t)}\right]^{\frac{-\theta}{\theta+\eta-\theta\eta}}, \qquad (33)$$

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

$$w(t) = (n\mu)^{\frac{1}{1+\psi}} \left(\frac{(\theta-1)\eta}{\theta}\right)^{\frac{\psi}{1+\psi}} \left[\sum_i \frac{1}{1+\tau_i(t)} \frac{\left[(1+\tau_i(t))\,/A_i(t)^{1/\eta}\right]^{\frac{\eta-\theta\eta}{\theta+\eta-\theta\eta}}}{[1+\overline{\tau}(t)]^{\frac{\eta-\theta\eta}{\theta+\eta-\theta\eta}}}\right]^{\frac{\psi}{1+\psi}}, \qquad (34)$$

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 $1+\overline{\tau}(t)$), 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

$$w(t) = (n\mu)^{\frac{1}{1+\psi}} \left(\frac{(\theta-1)\eta}{\theta \left(1+\widetilde{\tau}(t)\right)} \right)^{\frac{\psi}{1+\psi}}, \tag{35}$$

a function of deep parameters and individual tax rates. With this equilibrium wage we can derive the level of individual outputs and prices.

Now we turn to the derivation of growth rates. Rearranging $\frac{(\theta-1)\eta}{\theta\widehat{\zeta}(t)w(t)} = 1+\overline{\tau}(t)$, we can write $\left(\frac{C(t)}{nZ(t)}\right)^{\frac{1}{\eta}} = \widehat{\zeta}(t) = \frac{(\theta-1)\eta}{\theta w(t)[1+\overline{\tau}(t)]}$, which implies that the real GDP path is

$$C^*(t) = nZ(t) \left(\frac{(\theta-1)\eta}{\theta w(t) \left[1+\overline{\tau}(t)\right]} \right)^{\eta}. \tag{36}$$

Then the expected growth rates can be calculated easily. By the real GDP equation, we can write $E(g_C) = E(g_Z) - \eta \left[E(g_w) + E(g_{1+\overline{\tau}})\right]$, but from the wage equation we have

$$E(g_w) = -\frac{\psi}{1+\psi} E\left(g_{1+\widetilde{\tau}}\right) \approx -\frac{\psi}{1+\psi} E\left(g_{1+\overline{\tau}}\right), \tag{37}$$

so the real GDP-growth is

$$E(g_Y) = E(g_C) = E(g_Z) - \frac{\eta}{1+\psi} E\left(g_{1+\overline{\tau}}\right). \tag{38}$$

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

$$E(\pi) = E(g_P) = g_{PY} - E(g_Y) = g_{PY} - E(g_Z) + \frac{\eta}{1+\psi} E\left(g_{1+\overline{\tau}}\right). \tag{39}$$

Observe that the pass-through of tax changes into inflation is influenced by two deep parameters in this model. First, lower η (returns to scale parameter in the production function) decreases the pass-through by decreasing the extent of fall in real GDP (and the nominal GDP growth is given exogeneously). Second, lower ψ (inverse of the labor supply elasticity) increases the pass-through in the following channel: high 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 discretized state space for the solution.[7]

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:

$$\begin{pmatrix} \pi_s^f(t+1) \\ \log\zeta_s^f(t+1) \\ g_{Zs}(t+1) \\ \log\tau^1(t+1) \\ \log\tau^2(t+1) \\ \phi(t+1) \end{pmatrix} = A_0 + A_1 \cdot \begin{pmatrix} \pi_s(t) \\ \log\zeta_s(t) \\ g_{Zs}(t) \\ \log\tau^1(t) \\ \log\tau^2(t) \\ \phi(t) \end{pmatrix} + \Xi \cdot \begin{pmatrix} \epsilon_{\pi_s}(t+1) \\ \epsilon_{g_{Zs}}(t+1) \\ g_{\tau^1}(t+1) \\ g_{\tau^2}(t+1) \\ g_{\overline{\tau}}^{+}(t+1) \\ g_{\overline{\tau}}^{-}(t+1) \\ \Delta\phi(t+1) \end{pmatrix} \tag{40}$$

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 (23) using the flexible price solution. From this, it obtains a forecast for the $\zeta^f(t+1)$ using equation (25). Forecast for $g_{Zs}(t+1)$ is determined by equation (10) and the development of the tax rates (τ^1, τ^2) is simulated exogenously and from this $g_{\tau^1}, g_{\tau^2}, g_{\overline{\tau}}^{+}, g_{\overline{\tau}}^{-}$ 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 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 (23) 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 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

[7] 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.

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 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[8].

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**

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 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.

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

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

To estimate the inflation effect of 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. 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 2). 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). (VAT-increases and the VAT-decrease affected 46.9% and 51.0% – by CPI-weights – in the sample, which means that the comparison of the overall price effects is meaningful.)

Table 2: Inflation effects of VAT-changes

CPI category	**CPI weight**	**2004 Jan price effect**	**2006 Jan price effect**	**2006 Sep price effect**
Unprocessed food	16.121	2.10%	-0.88%	3.30%
Processed food	4.151	2.12%	-0.54%	4.37%
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

$$\pi_{st} = \sum_i \frac{\log P_{sit} - \log P_{si,t-1}}{N_i}, \tag{41}$$

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:

$$\pi_s = \sum_t \frac{\pi_{st}}{T}, \tag{42}$$

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

$$\overline{\pi} = \sum_s w_s \pi_s, \tag{43}$$

where w_s are CPI-weights (we use the CPI-weights in 2006). To avoid the effect of seasonal variation in monthly inflation rates, we used only 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:

$$\sigma_s^2 = \sum_t \frac{(\pi_{st} - \pi_s)^2}{T-1}, \tag{44}$$

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

$$\overline{\sigma} = \sum_s w_s \sigma_s. \tag{45}$$

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:

$$\overline{I}_s = \sum_t \sum_i \frac{I(\Delta P_{sit} \neq 0)}{N_s}, \tag{46}$$

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

$$\overline{I} = \sum_s w_s \overline{I}_s. \tag{47}$$

Again, to reduce the possible effect of seasonal variation in frequencies, we used 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:

$$\Delta P_s = \sum_{I(\Delta P_{sit} \neq 0)} \frac{|\Delta P_{sit}|}{N_{I_s}}, \tag{48}$$

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

$$\overline{\Delta P} = \sum_s w_s \Delta P_s. \tag{49}$$

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:

$$\rho_{p,s,i} = \frac{\sum_{I(\Delta P_{sit}\neq 0)} \left(\log p_{sit} - \log \overline{p_{sit}}\right)\left(\log p_{si,t-\tau_{sit}} - \log \overline{p_{sit}}\right)}{\sum_{I(\Delta P_{sit}\neq 0)} \left(\log p_{sit} - \log \overline{p_{sit}}\right)^2}, \tag{50}$$

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: $\rho_{p,s} = \sum\limits_i \rho_{p,s,i}/N_i$, while the overall autocorrelation of newly set relative prices is

$$\rho_p = \sum_s w_s \rho_{p,s}. \tag{51}$$

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.[9] Specifically, we estimated the following time-series regression for each representative item:

$$\pi_{st} = \beta_0 + \sum_{k=1}^{11} \beta_k (MONTH = k)_t + \beta_{12} VAT04J_t + \beta_{13} VAT06J_t + \beta_{14} VAT06S_t + \varepsilon_t, \tag{52}$$

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

$$\sum_s w_s \widehat{\beta}_{12,s}, \sum_s w_s \widehat{\beta}_{13,s}, \sum_s w_s \widehat{\beta}_{14,s}. \tag{53}$$

Table 3 reports the calculated moments for the main CPI-categories. We can interpret these figures as moments calculated from a "typical" representative item in the respective CPI-categories. We will estimate model parameters for each CPI-category to match these typical representative items.

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. Similarly to Klenow-Willis (2006), we calculate σ_p similarly to ρ_p:

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

[9] 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 2 and 3 they are sufficiently close to each other

Table 3: Estimated data moments

CPI category	$\overline{\pi}$	$\overline{\sigma}$	$\overline{I}$	$\overline{\Delta P}$	ρ_p	**VAT04j**	**VAT06j**	**VAT06s**
Proc. food	0.429%	0.91%	0.147	0.098	0.010	1.660	-0.770	3.471
Unproc. food	0.282%	2.64%	0.331	0.119	0.230	1.150	-0.137	4.724
Clothing	-0.119%	0.63%	0.069	0.152	-0.123	0.211	-1.085	0.212
Durable goods	-0.260%	0.51%	0.094	0.097	-0.100	0.118	-1.661	0.602
Other goods	0.125%	0.62%	0.100	0.108	-0.076	0.436	-1.032	0.881
Services	0.699%	0.67%	0.073	0.132	-0.031	0.495	-0.848	1.413
All	**0.324%**	**0.91%**	**0.130**	**0.113**	**-0.013**	**0.909**	**-0.870**	**2.200**

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

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

4 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. The current version of the paper is 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 from both tax brackets, and they show substantially different estimated asymmetry: while there does not seem to be any significant difference in the inflation effects of a unit tax increase and tax decrease in the processed food sector, 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 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 2002-01:2006:05. 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, 2006 predicts stronger strategic asymmetry in case of high θ. As the level of θ has similar effect as the level of menu cost: increasing θ increases the frequency and decreases the size of price changes, and decreasing the menu cost has the same effect, the model is not able to identify them separately.

In this version of the model, 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 to set the aggregate labor supply equal to 1/3.

4.2 Non-sectoral calibration

Table 4 and 5 contains the parameters and the moments of the non-sectoral calibration.

Table 4: Non-sectoral estimation

Parameters	σ_{gZ}	ρ_A	σ_A	ϕ_{NT}	ϕ_T	ψ	μ
	0.100	0.600	0.052	0.055	0.027	1	7
Forecast	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	R^2
	0.014	0.017	0.033	-.615	0.533	0.622	0.50
	(0.001)	(0.022)	(0.005)	(0.029)	(0.032)	(0.0336)	

Table 5: Moments of the non-sectoral estimation

	$\bar{\pi}$	$\sigma_{\bar{\pi}}$	ρ_p	σ_p	$\bar{I}_{NT}$	$\bar{I}_T$	ΔP_{NT}	ΔP_T	γ^+	γ^-
Data	0.003	0.009	-.013	0.114	0.120	0.314	0.114	0.010	1.104	0.394
Estimate	0.003	0.009	-.028	0.074	0.120	0.300	0.115	0.010	0.632	0.716

The Tables denote the average frequencies of monthly price changes as $\bar{I}_{NT}$ in case of no tax change and as $\bar{I}_T$ in case of tax change. The average absolute size of price changes are denoted as ΔP_{NT} in case of no tax change and ΔP_T in case of tax changes. γ^+ and γ^- denotes the inflation effects of a unit tax increase and decrease.

In this case the moments are calculated for the overall sample, as if the economy were homogeneous. The proportional weight of the products in the lower (15%) tax bracket hit by the (5%-points) tax increase is 37.1%, while the remaining 62.9% are in the higher (25%) tax bracket hit by the (5%-points) tax decrease. The inflation effect of the tax increase is estimated to be 2.2%, while the effect of the tax decrease is estimated to be -0.87%. After controlling for the weights of the groups of the products and the sizes of the tax increases, we find a significantly different effects of a unit tax change: it is 1.1 and 0.39 in case of a unit tax increase and the tax decrease respectively.

The results show that the model is fairly good at hitting most of the moments. The overall frequency of price change is 12.0% and the size of the price changes are 11.5% which are somewhat different as was found in the CPI database in other countries (Nakamura and Steinsson, 2007 reports median frequency of 21.1% and size at 8.5% for the US data) showing that our subsample 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 fairly persistent ($\rho_A = 0.6$) idiosyncratic shocks with large conditional volatility ($\sigma_A = 5.2\%$) 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%). In order to hit the larger frequency and lower size of price changes in case of tax changes, the menu cost in case of tax changes needs to be slightly more than half of the value of a non-tax change menu cost. It can be considered reasonable, 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 – an order of magnitude larger (around 1.2%) than the physical costs of price changes (0.05%) – which are the same in both cases.

The average cross-sectional variance of the relative prices σ_p is the moment, which is significantly missed. 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 cross sectional relative price dispersion.

Although the model hits most of the moments, it 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.

4.3 Sectoral calibration

The estimation for the processed food sector (excluding alcohol and tobacco with frequent product specific tax changes) is found in Table 6 and 7.

The processed food sector is the largest sector in our sample with 128 items and 16.1% CPI weight, while it is the second largest after the services sector in the CPI basket. Within

Table 6: Processed food sector estimation

Parameters	σ_{g_Z}	ρ_A	σ_A	ϕ_T	ϕ_{NT}	ψ	μ
	0.06	0.675	0.045	0.038	0.014	0.00	6.75
Forecast	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	R^2
	0.008	0.031	0.007	-.692	0.882	0.82	0.78
	(0.001)	(0.012)	(0.006)	(0.024)	(0.02)	(0.02)	

Table 7: Moments of the processed food sector estimation

	$\bar{\pi}$	$\sigma_{\bar{\pi}}$	ρ_p	σ_p	$\bar{I}_{NT}$	$\bar{I}_T$	ΔP_{NT}	ΔP_T	γ^+	γ^-
Data	0.004	0.009	0.01	0.094	0.133	0.405	0.099	0.090	0.839	1.044
Estimate	0.004	0.009	0.07	0.066	0.133	0.402	0.099	0.082	0.581	0.927

the sector, 78.8% of the products are in the lower tax brackets influenced by the tax increase, with 21.2% influenced by the tax decrease. The average inflation rate (5.3% yearly rate) in this sector is slightly larger than the average inflation (4.5% yearly rate), but the average frequency of price changes are lower (13.4%) than in the whole sample.

The model is able to hit most of the moments fairly successfully – the cross sectional variance of the relative prices are still underestimated in this case –, it estimates the volatility of the idiosyncratic shocks to be lower and the menu cost to be slightly larger than in the non-sectoral estimation.

The 2006:09 tax increase had an estimated 3.47% effect on the sectoral inflation, while the 2006:01 tax drop decreased the inflation rate by 0.77%. After controlling for the asymmetric weights of the products in the two tax brackets, we find the coefficients of the inflation effects of unit tax increases being 1.04 and 0.84 respectively. The model underestimates the sizes of the tax shocks (even with fully flexible labor supply with $\psi = 0$), and somewhat overestimates the asymmetry by predicting coefficients with 0.93 and 0.58 respectively.

Table 8 and 9 contains the parameter estimates and moments for the services sector.

Table 8: Services sector estimation

Parameters	σ_{g_Z}	ρ_A	σ_A	ϕ_T	ϕ_{NT}	ψ	μ
	0.013	0.35	0.06	0.041	0.11	0.1	13
Forecast	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	R^2
	0.013	0.014	0.025	-.544	0.882	0.367	0.60
	(0.002)	(0.015)	(0.006)	(0.09)	(0.019)	(0.02)	

The services sector, which is the largest sector in the CPI basket, is the second largest sector in our sample with 78 items and 9.8% CPI-weight. Within the sector, 32.1% is the weight of the products in the lower tax bracket, with the remaining 67.9% facing larger tax rates. The average sectoral inflation rate is substantially higher (7.8% yearly rate) than the average inflation rate, while the frequency of the price changes are much lower (7.3%) than the average.

Table 9: Moments of the services sector estimation

	$\bar{\pi}$	$\sigma_{\bar{\pi}}$	ρ_p	σ_p	$\bar{I}_{NT}$	$\bar{I}_T$	ΔP_{NT}	ΔP_T	γ^+	γ^-
Data	0.007	0.007	-.031	0.123	0.063	0.261	0.138	0.111	1.064	0.300
Estimate	0.007	0.007	0.033	0.070	0.063	0.261	0.133	0.109	0.996	0.439

In order to hit the targeted moments, the variance of the idiosyncratic shocks need to be less volatile and less persistent than the average, and the menu cost to be much higher (11%) compared to the 3.8% in the non-sectoral case.

The inflation effect of the 2006:09 tax increase is estimated to be 1.41%, while the 2006:01 tax drop decreased the sectoral inflation rate by 0.85%. After controlling for the weights of the products in the different tax brackets and for the size of the tax changes, we find a substantial asymmetry in the inflation effects between the positive and negative tax changes, the coefficients of the unit tax changes are 1.64 and 0.299 respectively. The model also finds a substantial asymmetry for these parameters, it somewhat underestimates the true magnitudes: it predicts 0.996 and 0.439 as coefficients for the tax increase and decrease respectively.

4.4 Reasons of the sectoral asymmetry

For our parametrization, the sole economically significant reason of the observed sectoral asymmetry is the trend inflation, and we have found no sizable effects of the strategic considerations emphasized by Devereux and Siu, 2007. Running counterfactual experiments made by setting the average inflation rate to zero resulted in no significant asymmetry in any of the sectors.

These results suggest that even with fairly high level of competition ($\theta = 11$), the 5% tax changes were not large enough to induce strategic asymmetry. Though non-linear effects of the larger tax decrease can counteract the fact that it was a *negative* shock, experiments with equal tax changes do not support this argument, as these estimates also reject the existence of any 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 evaluate various sources of pricing asymmetries as a response to major VAT changes. The paper argued that the model is rich enough to incorporate the major sources of asymmetry, and the various moments provide sufficient information to identify most of the parameter values. The paper found that under the current parametrization, the reason of the pricing asymmetry is the sectoral trend inflation, as was suggested by Ball and Mankiw, 1994, and the strategic asymmetry emphasized recently by Devereux and Siu, 2007 has no effect for the tax shocks of these size.

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