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Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

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Kiel Institute for the World Economy &
Christian-Albrechts-University Kiel

E-mail:
steffen.ahrens@ifw-kiel.de
sacht@economics.uni-kiel.de

Estimating a High-Frequency New Keynesian Phillips Curve

Steffen Ahrens*and Stephen Sacht†

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Abstract

This paper estimates a high-frequency New Keynesian Phillips curve via the Generalized Method of Moments. Allowing for higher-than-usual frequencies strongly mitigates the well-known problems of small-sample biases and structural breaks. Applying a daily frequency allows us to obtain event-specific estimates for the Calvo parameter of nominal rigidity - for instance for the recent financial and economic crisis -, which can be easily transformed into their weekly, monthly and quarterly equivalences to be employed for the analysis of event-specific monetary and fiscal policy. With Argentine data from the end of 2007 to the beginning of 2011, we find the daily Calvo parameter to vary in a very close range around 0.97, which implies averagely fixed prices of approximately 40 days or equivalently one and a half month or a little less than half a quarter. This has strong implication for the modeling of monetary policy analysis since it implies that at a quarterly frequency a flexible price model has to be employed. In the same vein, to analyze monetary policy in a sticky price framework, a monthly model seems more appropriate.

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*Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany; Christian-Albrechts-University Kiel. Email: steffen.ahrens@ifw-kiel.de

†Corresponding author. Department of Economics, Christian-Albrechts-University Kiel, Olshausenstraße 40, 24118 Kiel, Germany. Email: sacht@economics.uni-kiel.de

1 Introduction

Since the late 1990's, the estimation of the New Keynesian Phillips curve (NKPC for short) derived from Calvo (1983) staggered prices has been prominent in the macro literature. Economists are interested in the accuracy of the NKPC to resemble real time data and the information on the structural parameters, especially the Calvo parameter on nominal rigidity. A major drawback in this analysis, however, is the low frequency. Usually, a NKPC is estimated applying Hansen's (1982) Generalized Method of Moments (GMM) to quarterly observations. Fuhrer et al. (1995) show that GMM suffers from a small sample bias with the consequence that GMM demands a critical amount of observations to achieve reliable estimates. Lindé (2005) argues that it takes approximately 1,000 observations for GMM to converge to the true values when estimating a NKPC. Having four observations per year, to obtain that many observations, a time span of 250 years is necessary. Moreover, going back 50 or 100 years from now covers many different economic conditions such as the Great Depression, the high inflation periods after the oil price shocks, low inflation periods such as the Great Moderation, and the current financial and economic crisis, i.e. the so called Great Recession. Assuming the behavioral deep parameters to remain constant over such long periods characterized by that many structural breaks certainly violates the Lucas (1976) critique.

Furthermore, recent evidence by, among others, Fernández-Villaverde and Rubio-Ramírez (2007) and Ahrens and Hartmann (2011), has documented that the Calvo parameter is not a structural parameter, but that it is negatively correlated to the level of trend inflation. An opposing view is taken by Cogley and Sbordone (2005), who argue that - controlled for trend inflation - the Calvo parameter can be treated as a constant over long sample periods. In their empirical assessment they give proof that variation in the Calvo parameter due to trend inflation is minimal and statistically not significant. Even though, being a strong result, it is, however, only of little relevance for monetary policy analysis as it is conducted today. Most contributions analyze optimal monetary policy rules under the assumption of a zero inflation steady state and thereby omitting trend inflation by assumption. As a consequence, assuming the Calvo parameter to be constant might be certainly misleading.

The contribution of this paper is to allow for the estimation of the Calvo parameter at a much higher frequency and thereby reducing the risk of small sample bias and structural breaks imminently. To account for such problems, we apply the standard GMM approach to estimating the NKPC for a higher frequency. We are then able to take the estimation results for the daily Calvo parameter and transform them into pseudo-quarterly observations by simply applying the rules described in Franke and Sacht (2010) in order to derive a high-frequency NKPC, i.e. we account for the fact that the frequency-dependent parameters should be suitably adjusted. In particular we use daily inflation data from the end of 2007 to the beginning of 2011 provided by the *Billion Prices Project* at MIT Sloan. Doing so, our data comprises only three years of observations, but contains 830 data points. This is very close to the value suggested by Lindé (2005). Furthermore, in only one year from now, we will be able to clearly supersede the mark of 1,000 observations. Our approach gives us several advantages towards the standard quarterly analysis of the NKPC. First, we are able to focus on specific events such as the financial and economic crisis and second estimate accurately the respective Calvo parameter with a large amount of observations. This daily point estimate can then be transformed into lower frequency equivalence and used to calibrate business cycle models on a monthly or quarterly frequency. In doing so, monetary policy analysis is derived from current economic conditions for current economic conditions.

This study focuses on Argentina. First, Argentina is the only country for which daily observations of the consumer price index are freely available from the *Billion Prices Project* at MIT Sloan. Second, Argentina is an example par excellence for a country sample that suffers from structural breaks. Even in a time span as short as the last two decades, D'Amato et al. (2007) identify two substantial structural breaks in inflation due to shifts in the Argentine monetary regime. The first structural break was engendered by the external and financial crisis in 1982, which resulted in hyperinflation and finally in the establishment of the Convertibility Act in 1991. The second structural break occurred due to the abandonment of the Convertibility Act in 2002 as a consequence of the sharp depreciation in the early 2000's currency crisis. It is also very likely that the financial and economic crisis of 2007 marks another structural break in Argentine inflation.

Applying our method to Argentine data we find the daily Calvo parameter to vary in a very close range around 0.97, which implies averagely fixed prices of approximately 40 days or equivalently one and a half month or a little less than half a quarter. These values are well in line with micro evidence for Argentina from Cavallo (2011). Our results have strong implication for the modeling of monetary policy analysis. First, they imply that the frequency of price adjustments has to be calibrated much higher for Argentina compared to the United States or the Euro Area. Second a most important, an average price stickiness of one half quarter means that at a quarterly frequency a flexible price model has to be applied to analyze monetary policy. In the same vein, to analyze monetary policy in a sticky price framework, a monthly model (like the equivalent variation of the standard 3-equation New Keynesian model (NKM) in Franke and Sacht (2010)) seems more appropriate.

Modeling the impact of different period lengths on the dynamics of the current workhorse-model used for monetary and fiscal policy evaluation, the NKM with sticky prices (and wages), has been done by Flaschel et. al. (2008), Franke and Sacht (2010) as well as Anagnostopoulos and Giannitsarou (2010) in the first place. Franke and Sacht (2010) showed that by diverging from the standard assumption of the baseline period length to be a quarter dramatic changes in the dynamic properties of the model follow. In particular the authors state that while determinacy of the model remains unaffected, the impulse response functions differ in a quantitative and qualitative way just by increasing the frequency of decision making (i.e. assuming a monthly, weekly or daily length of the period).

Moreover, there is an increasing interest in the literature on the high-frequency behavior of price changes. In a scanner data study for British supermarkets, Ellis (2009) shows that the frequency of price changes is considerably higher in high frequency studies compared to the traditional monthly or quarterly consumer price index analysis undertaken by statistical agencies. Furthermore, Ellis (2009) shows that lower frequency data tends to overstate the true price stickiness. Abe and Tonigi (2010) strongly support this conclusion for the Japanese market. Additionally, Kehoe and Midrigan (2007) find very short average price stickiness spells for the suburban Chicago as Cavallo (2011) finds this for Argentina, Brazil, Chile, and Colombia.

The remainder of the paper is organized as follows. In the next section we derive the open economy version of the high-frequency NKPC. In section 3 we first describe the data as well as the estimation technique and present the empirical results. Hence, we discuss the implications of our results for monetary policy analysis in Argentina. Finally, section 4 concludes.

2 The high-frequency New-Keynesian Phillips Curve

An extensive analysis of the microfoundation of the *quarterly* NKPC under the standard assumption of the Calvo price setting scheme in open economies can be found e.g. in Galí (2008) and Walsh (2010). In contrast to the standard literature we consider the underlying period length denoted by $0 < h_i \leq 1$ explicitly. The subscripts $i = \{\text{d=daily, m=monthly, q=quarterly}\}$ indicate the time unites relative to the benchmark interval which is fixed as a quarter ($h_q = 1$) following Flaschel et. al. (2008) and Franke and Sacht (2010). Hence we generally allow the representative firm to make its decisions and carry out the corresponding transactions every h_i quarters, e.g. in daily magnitudes ($h_d = 1/75$) since a quarter consists on 75 days on average (excluding weekends). To derive the NKPC in its high-frequency representation the corresponding frequency-dependent parameters therefore have to be suitably adjusted.[1] In particular the values of two structural parameters which enter the NKPC are dependent on the frequency of decision making.

First, within a period of length h_i the fraction of firms resetting their price will be $h_i(1-\theta)$ where the symbol θ is retained for the constituent Calvo price stickiness parameter from the quarterly setting. According to that we have

$$\theta(h_i) = 1 - h_i(1-\theta) \tag{1}$$

This means if the price of a representative firm remains unchanged with a probability θ within a quarter, a corresponding $\theta(h_i)$-fraction of firms will not be able to adjust their prices in the subinterval $[t + h_i k, t + h_i(k+1))$ as we consider a higher frequency in decision making ($h_i < 1$), where $t = 0, \dots, \infty$ denotes the quarterly ticks, while $k = 0, \dots, \left(h_i^{-1} - 1\right)$ expresses the intra-quarter ticks.[2] Second the discount factor β becomes

$$\beta(h_i) = 1/(1 + h_i\rho) \tag{2}$$

since e.g. a discount rate ρ of 1.01 % per quarter means that a certain asset is discounted by h_i times 1.01 % over the period $[t+h_i k, t+h_i(k+1))$. However we are able to present a more general specification of the transition equations (1) and (2). Since the subintervals (a day or a month) are proportional to the benchmark interval (a quarter) it is possible to extract the value of the frequent-dependent parameter from one subinterval ($\theta(h_i)$) out of another ($\theta(h_j)$). To see this one may apply the following formula

$$\theta(h_i) = 1 - \lambda_{i,j}(1 - \theta(h_j)) \tag{3}$$

with $\lambda_{i,j} = h_i/h_j$ (also consider that now $\lambda_{i,j}(1-\theta(h_j))$ holds). For instance given the value of the Calvo parameter in daily magnitudes $\theta(h_i = h_d)$ (as a result of our estimations in chapter 3) we are interested in the value of

[1] The procedure can also be found in the modeling of search and matching processes; see, e.g. Mortensen (1986) and Rogerson et. al. (2005). Anagnostopoulos and Giannitsarou (2010) analyze local stability under consideration of changes in the period length quite similar to Flaschel et. al. (2008).

[2] Note that the stickiness remains the same in the sense that on average a firm is allowed to reset the price every $1/[1-\theta(h_i)]$ periods of length h_i which, independently of h_i,means every $h_i/[1-\theta(h_i)] = h_i/[1-1+h_i(1-\theta)] = 1/(1-\theta)$ quarters.

the Calvo parameter in monthly $\theta(h_j = h_m)$ magnitudes instead. Hence for $h_d = 1/75$ and $h_m = 1/3$ (for the latter note that a quarter consists on 3 months) the transition from monthly to daily magnitudes is done under consideration of $\lambda_{d,m} = h_d/h_m = \frac{1/75}{1/3} = 1/25$ and the value for $\theta(h_m)$ is simply given by

$$\theta(h_m) = 1 - \frac{1}{\lambda_{d,m}}(1 - \theta(h_d)) \quad (4)$$

Obviously in the benchmark case of $h_j = h_q = 1$ equation (3) will collapse into (1). Accordingly equation (2) now reads

$$\beta(h_i) = 1/(1 + \lambda_{i,j}\rho(h_j)) \quad (5)$$

Taking the expressions (3) and (5) into account a representative firm is facing the following optimization problem

$$\min_{z_t} V_t = \sum_{k=0}^{\infty} \beta(h_i)^k (z_{t+h_ik} - p^*_{t+h_ik})^2 \quad (6)$$

It is the aim of a representative firm to minimize the expected price distortion (deviation of future log-price z_{t+h_ik} from optimal log-price level $p^*_{t+h_ik}$, i.e. the price firms would set in period $t + h_ik$ in the absence of price rigidity) given above by changing its own price z_{t+h_ik}.[3] Equation (6) can be reformulated into

$$\min_{z_t} V_t = \sum_{k=0}^{\infty} (\theta(h_i)\beta(h_i))^k (z_t - p^*_{t+h_ik})^2 \quad (7)$$

The aggregate price level p_t is the weighted sum of the desired price level set by a $\lambda_{i,j}(1-\theta(h_j))$-fraction of firms which are able to choose their reset price z_t and the lagged price level due to a fraction of $\theta(h_i)$ (corresponding to a $\theta(h_i)$-fraction of firms which are not in the position to change their price):

$$p_{t+h_ik} = \theta(h_i)p_{t+h_i(k-1)} + \lambda_{i,j}(1 - \theta(h_j))z_{t+h_ik} \quad (8)$$

Consider $p^*_{t+h_ik} = \mu + mc_{t+h_ik}$, i.e. the optimal price set by the firm under monopolistic competition is the sum of the nominal marginal costs mc_{t+h_ik} and the desired mark-up μ, the high frequency version of the NKPC is then given by

$$\pi_{t+h_ik} = \beta(h_i)\pi_{t+h_i(k+1)} + \frac{(1 - \theta(h_i))[1 - \theta(h_i)\beta(h_i)]}{\theta(h_i)}(\mu + mc_{t+h_ik} - p_{t+h_ik}) \quad (9)$$

[3]Note that prices are expressed in *domestic* goods. Furthermore, the expectations operator regarding future values of the variable ψ is omitted ($E_{t+h_ik}(\psi_{t+h_i(k+1)}) \equiv \psi_{t+h_i(k+1)}$).

where $\pi_{t+h_ik} = p_{t+h_ik} - p_{t+h_i(k-1)}$ denotes the domestic inflation rate.[4] Up to this point it can be seen that the structure of the NKPC (in quarterly or lower frequencies respectively) does not differ in open and closed economies (e.g. Galí (2008), Clarida et. al. (2002) or Walsh (2010)). The last term in (9) can be substituted by the expressions for the domestic (y_{t+h_ik}) and foreign ($y^F_{t+h_ik}$) output gap:

$$\begin{aligned} y_{t+h_ik} &= x_{t+h_ik} - \tilde{x} && (10) \\ y^F_{t+h_ik} &= x^F_{t+h_ik} - \tilde{x}^F && (11) \end{aligned}$$

where x_{t+h_ik} ($x^F_{t+h_ik}$) and $\tilde{x}$ ($\tilde{x}^F$) stand for domestic (foreign) output level and potential output respectively. Hence

$$\pi_{t+h_ik} = \beta(h_i)\pi_{t+h_i(k+1)} + \frac{(1-\theta(h_i))[1-\theta(h_i)\beta(h_i)]}{\theta(h_i)} \cdot [(\sigma_\alpha + \eta)y_{t+h_ik} - (\sigma_\alpha - \sigma)y^F_{t+h_ik}] \quad (12)$$

where $\sigma_\alpha = \sigma[1 - \alpha + \alpha(\sigma\gamma + (1-\alpha)(\sigma\chi - 1))]^{-1}$ is a function of the degree of openness α, the substitutability between domestic and foreign goods from the viewpoint of the domestic consumer χ, the substitutability between goods produced in different foreign countries γ and the intertemporal elasticity of substitution in consumption of domestic goods σ. Note that there is no change in the structure of the NKPC in (12) compared to (9) concerning the period length because the corresponding parameters σ_α and η (i.e. the intertemporal elasticity of substitution in labour) are independent of h.

Considering (9) and (12) the following problem arises: Neither data on the real marginal costs ($mc_{t+h_ik} - p_{t+h_ik}$) as well as on the markup μ nor on both output gaps are available on a daily basis. In order to get an appropriate expression for a daily NKPC we make use of the (log-linearized) terms of trade

$$s_{t+h_ik} = e_{t+h_ik} + p^F_{t+h_ik} - p_{t+h_ik} \quad (13)$$

where e_{t+h_ik} denotes the bilateral nominal exchange rate and $p^F_{t+h_ik}$ the price for foreign goods. Furthermore we claim that there exists a relationship between the *terms of trade gap* (Clarida et. al. (2001) and Clarida et. al. (2002)) and both (domestic and foreign) output gaps:

$$\frac{1}{\sigma_\alpha}(s_{t+h_ik} - \tilde{s}(x^f_{t+h_ik})) = y_{t+h_ik} - y^F_{t+h_ik} \quad (14)$$

[4] In order to reproduce the following steps the interested reader is referred to Galí (2008). However it is not necessary to spell out the details that lead from the microfoundations to the structural high-frequency NKPC since all of the agents' optimization procedures and the subsequent mathematical operations go through unaltered (Franke and Sacht (2010)). Nevertheless a detailed derivation of the high-frequency NKPC is available upon request.

where $\tilde{s}(x^f_{t+h_ik})$ stands for the terms of trade in the steady state which is a non-linear function of the foreign output level and the technology parameter a_{t+h_ik}. To go one step further we assume that shocks to the *foreign* output level lead to negligible small deviations in the corresponding output gap over the observed time horizon ($x^F_{t+h_ik} \approx 0$ while $\tilde{x}^F = 0$). Hence the expression for $y^F_{t+h_ik}$ and $\tilde{s}(x^f_{t+h_ik})$ can be omitted.[5] By applying (13) and (14) on (12) we are able to derive an open economy NKPC which depends on the *terms of trade*:[6]

$$\pi_{t+h_ik} = \beta(h_i)\pi_{t+h_i(k+1)} + \frac{(1-\theta(h_i))[1-\theta(h_i)\beta(h_i)]}{\theta(h_i)}\psi s_{t+h_ik}, \tag{15}$$

where $\psi = 1 + \frac{\eta}{\sigma_\alpha}$. Since data on movements in the terms of trade are also not available on a daily bases we consider two types of the high-frequency version of the NKPC. Under consideration of the *uncovered interest parity*

$$s_{t+h_ik} = e_{t+h_i(k+1)} + r^F_{t+h_ik} - r_{t+h_ik} - p_{t+h_ik} + p^F_{t+h_ik} \tag{16}$$

where r_{t+h_ik} ($r^F_{t+h_ik}$) denotes the domestic (foreign) nominal interest rate, this leads to the following expression denoted as *Type I* NKPC:

$$\pi_{t+h_ik} = \beta(h_i)\pi_{t+h_i(k+1)} + \frac{(1-\theta(h_i))[1-\theta(h_i)\beta(h_i)]}{\theta(h_i)} \cdot\psi(e_{t+h_i(k+1)} + r^F_{t+h_ik} - r_{t+h_ik} - p_{t+h_ik} + p^F_{t+h_ik}) \tag{17}$$

Hence within this specification the driving forces of domestic inflation are the expected bilateral nominal exchange rate, the domestic nominal interest rate, the domestic and foreign price level. A specification where domestic inflation is driven by the *real bilateral exchange rate* only is obtained by following Monacelli (2004). Within his investigation he claims that only a negligible small share of domestic goods is consumed in the rest of the world and that

[5]One may argue that this kind of assumption is too strong because times series of output for e.g. the US show remarkable deviations from the potential output over the last two years due to the economic downturn relating to the Great Recession. However Furceri and Mourougane (2009) find that the occurrence of a financial crisis negatively and permanently affects also potential output. In particular, financial crises are estimated to lower potential output by around 1.5 to 2.4 % on average. In addition Jannsen and Scheide (2010) provide empirical evidence for a shift in potential output (represented by the growth path of GDP with a log-linear trend) due to the Great Recession in the US by more than 2 %. Since more evidence on the impact of financial crisis on potential output (and hence on the net effect for the output gap) seems to be rare up to this point our assumption seems justified.

[6]Furthermore due to our empirical analysis we account for a white noise innovation to inflation only. Therefore no technology shock appears ($a_t = 0$).

foreign inflation is zero which implies $p^F_{t+h_ik} = 0$. Therefore, the so called *Type II* NKPC is given by

$$\pi_{t+h_ik} = \beta(h_i)\pi_{t+h_i(k+1)} + \frac{(1-\theta(h_i))[1-\theta(h_i)\beta(h_i)]}{\theta(h_i)}\psi(e_{t+h_ik} - p_{t+h_ik}) \quad (18)$$

Note that the time series for domestic and foreign prices (and, of course, for the domestic inflation rate), the interest rates and for the bilateral exchange rate are all available on daily frequencies. Hence both *Type I* and *Type II* NKPCs can be seen as high frequency Phillips curves (hf-NKPC) in *daily* magnitudes. In the following section we show that this kind of specifications are highly sufficient to estimate the Calvo parameter of price stickiness θ from the beginning of 2007 up to now just under the consideration of daily time series data.

3 Empirical Exercise

In this section, we analyze the empirical implications of the high-frequency NKPC for the adjustment speed of prices on a daily basis. We define Argentina as the *domestic* economy. Following D'Amato and Garegnani (2009), the *foreign* economy comprises Argentina's three most important trading partners Brazil, the Euro Area, and the United States, where Brazil gets assigned the largest weight in the basket. For robustness, we also check for bilateral arrangements with both Brazil and the United States being the foreign economy. The choice for a dominating Brazil can be justified by Brazil's relative importance in mutual trade flows arising from the geographical proximity and the joint membership in the *Mercado Común del Sur* (Mercosur), the Southern Common Market. Being Argentina's number one trading partner, Brazil accounts for approximately 22% of exports and roughly one third of all imports. These numbers strongly outweigh the second most important trading partner the United States, who account for only 8% of exports and 15% of imports (World Bank, 2010). Nevertheless, to test for robustness, we also report results for the United States being the *foreign* country.

3.1 Data

The data set comprises daily observations for Argentina, Brazil and the United States from 12-03-2007 to 04-02-2011. For proper identification, mnemonic codes are presented in parentheses after each variables.

Argentine inflation is defined as annualized daily percentage change in the consumer price index. The consumer price index is provided by *www.inflacionverdadera.com*, which is a subproject from the *Billion Prices Project* at

MIT Sloan. In the empirical exercise, we apply two alternative definitions of the consumer price index (CPI). The first consumer price index is based on a consumption basket (indicecanastabasica) and the second consumer price index comprises solely food and beverages (indicealimentosybebidas). The underlying price data to both these indices are collected on a daily basis from large supermarkets in the metropolitan area of Buenos Aires.[7]

All remaining data are taken from Datastream®. In particular, we apply the Argentine Peso to EURO and US dollar exchange rates (TEARSSP) and (TDARSSP), respectively. Additionally, we derive the Argentine Peso to Brazilian Real exchange rate from the exchange rates for the Argentine Peso to the United States Dollar and the Brazilian Real to the United States Dollar (TDBRLSP). As home and foreign interest rates, we apply the Argentine 1day Buenos Aires Interbank Offer Rate (AGIBK1D) and the United States Federal Funds Rate (USFDTRG), respectively. In the Robustness exercise we also apply the Brazilian Sistema Especial de Liquidação e de Custódia (Selic) Base Interest Rate (BROVERN).

3.2 Calibration

We calibrate the real interest rate to 5.2% according to World Development Indicators reported by the World Bank (2009), which yields a quarterly discount factor $\rho = 0.013$. All remaining parameters are calibrated according to Escudé (2009), who estimates a medium scale open economy DSGE model for Argentina. Thus, we set the intertemporal elasticity of substitution for domestic goods $\sigma = 1.902$ and the intertemporal elasticity of labor $\chi = 0.7$. Domestic and foreign goods are assumed to be imperfect substitutes as well as are the different varieties produced in the foreign country. The elasticities of substitution between the former is set to be $\eta = 1.175$ while the latter is given by $\gamma = 0.990$. The degree of openness is calibrated to match Argentina's share of foreign goods in consumption, i.e. $\alpha = 0.134$. For robustness, we juxtapose the results for an earlier calibration from Escudé (2007) for Argentina and an alternative calibration from Galí and Monacelli (2005), which represents a standard calibration in the literature. The parameter values are summarized in Table 1.

[7]For a thorough discussion of the methodology of the *Billion Prices Project* at MIT Sloan, refer to Cavallo (2011), Cavallo and Rigobon (2011), www.inflacionverdadera.com, and www.thebillionpricesproject.com.

Table 1: Calibration

	Escudé (2009)	Galí and Monacelli (2005)	Escudé (2007)
σ	1.902	1.000	4.960
χ	0.700	3.000	1.000
η	1.175	1.000	1.194
γ	0.990	1.000	3.500
α	0.139	0.100	0.112
ρ	0.013	0.013	0.013

3.3 Estimation Methodology

The empirical analysis nests on the high-frequency NKPC given by the equations (17) and (18). By substitution of the day-by-day expectational error $\epsilon_{t+h_ik} = \beta(h_i)(E_t[\pi_{t+h_i(k+1)}] - \pi_{t+h_i(k+1)})$ we obtain a regression equation of the form

$$\pi_{t+h_ik} = \beta(h_i)\pi_{t+h_i(k+1)} + \frac{(1-\theta(h_i))[1-\theta(h_i)\beta(h_i)]}{\theta(h_i)}\psi\xi_{i,t+h_ik} + \epsilon_{t+h_ik}. \quad (19)$$

with $\xi_i = \{\xi_1, \xi_2\} = \{(e_{t+h_i(k+1)} + r^F_{t+h_ik} - r_{t+h_ik} - p_{t+h_ik}), e_{t+h_ik} - p_{t+h_ik}\}$. Furthermore, $t = 0, \ldots, 13$ denotes the quarterly ticks,[8] while the daily intra-quarter ticks are expressed by $k = 0, \ldots, \left(h_i^{-1} - 1 = 74\right)$.

McCallum (1976) shows that under rational expectations the prediction error of future inflation ϵ_{t+h_ik} is uncorrelated to the information set available to the forecaster $\mathbf{z}_{t+h_ik}$, which comprises information dated at time $t + h_ik$ or earlier. This assumption implies that $E_{t+h_ik}[\epsilon_{t+h_ik}\mathbf{z}_{t+h_ik}] = 0$. Applying this condition to equation (19), we obtain

$$\begin{aligned} E_{t+h_ik}\Big[\Big(&\theta(h)\pi_{t+h_ik} - \theta(h)\beta(h)\pi_{t+h_i(k+1)} \\ &-(1-\theta(h))(1-\theta(h)\beta(h))\psi\xi_{i,t+h_ik}\Big)\,\mathbf{z}_{t+h_ik}\Big] = 0 \end{aligned} \quad (20)$$

with $\mathbf{z}_{t+h_ik} = (\pi_{t+h_i(k-1)}, \pi_{t+h_i(k-2)})'$ being a vector of past information. According to McCallum (1976) such an orthogonality condition can be consistently estimated with an instrument variable technique. The latter is standard in the literature since the prominent contribution of Galí and Gertler (1999), we apply Hansen's (1982) Generalized Method of Moments to estimate the structural parameter $\theta(h_d)$.

[8] The first observation in each quarter.

Table 2: Price Adjustment Frequency in Argentina

	Calvo parameter			Average duration of fix prices in...		
	$\theta\,(h_d)$	$\theta\,(h_m)$	$\theta(h_q)$	...days	...months	...quarters
Consumption basket:						
Type 1	0.9810 (0.0546)	0.5250	$--^*$	53	2.11	0.70
Type 2	0.9725 (0.0651)	0.3125	$--^*$	36	1.45	0.49
Food and beverages:						
Type 1	0.9760 (0.0327)	0.4000	$--^*$	42	1.67	0.56
Type 2	0.9660 (0.0428)	0.1500	$--^*$	29	1.18	0.39

Note: The daily frequency of price adjustments $\theta(h_d)$ is directly estimated with GMM using the equations (17) and (18). The monthly and quarterly frequencies $\theta(h_m)$ and $\theta(h_q)$ as well as the average duration of fix prices in months and quarters are given by applying the equation (21) respectively. The superscript * implies that the quarterly Calvo parameter cannot be determined (since $\theta(h_q) < 0$), i.e. prices change at least once within every quarter.

3.4 Results

In this section we discuss the results from the empirical exercise. The point estimates for the daily Calvo parameter $\theta\,(h_d)$ are summarized in the first column of Table 2.

Note up front that the estimates for θ_d lie remarkably close to each other in an interval between $[0.9660; 0.9810]$, even though the admissible range for economically relevant values of θ_d is from zero to unity and their are no restrictions imposed on this parameter. Since Calvo staggering follows a Poisson process, prices are fixed on average for $\mathcal{D} = \frac{1}{1-\theta_d}$ days. With the underlying concept of inflation being based on a broad consumption basket the average duration implied by the high frequency NKPC lies at approximately 53 days for the Type I and at 36 days for the Type II hf-NKPC. This is at the lower end, but still in line with microeconomic evidence on high frequency pricing in Argentina provided by Cavallo (2011). Applying an inflation measure, based solely on food and beverages, price changes occur much more often compared to the basket based measure. In particular, for the Type I hf-NKPC prices remain fixed on average for 42 days, while it is 29 days for the Type II hf-NKPC. The increased volatility in food and beverages price changes across both types of hf-NKPC is in line with micro-evidence of price changes in Japanese supermarkets reported by Abe and Tonogi (2010). The authors show that the probability of price changes is generally higher for foods compared to other categories and assess that this comes from the fact that they are perishable. And indeed, Ellis (2009) finds highly perishable goods, such as fresh fruits and vegetables, to have the highest probability of price changes among a wide variety of products.

On of the major contributions of this paper is that we can use the daily information to derive lower frequency information, such as monthly or quarterly by simply employing the daily point estimate to the following equation:

$$\theta(h_j) = 1 - \frac{1}{\lambda_{d,j}} \left(1 - \theta(h_d)\right) \tag{21}$$

where we refer directly to equation (4) with $\lambda_{d,j} = \frac{h_d}{h_j}$ and $j = m, q$.[9] The results for monthly and quarterly conversion are given in the second and third column of Table 2. According to equation (21), a daily probability of not being able to reset the price $\theta_d = 0.9810$ is equivalent to a monthly probability of not being able to reset the price of $\theta_m = 0.5250$, which is equivalent to an average duration of fixed prices of a little more than two months. Since $\theta(h_j) = f(\theta(h_d))$ with $f' > 0$, $\theta(h_j)$ decreases with lower rates for θ_d and therefore, the monthly probability of price changes reduces to $\theta_m = 0.4$, implying an average duration of fixed prices of 1.67 months.

The price adjustment speed estimated from the data implies that a quarterly Calvo parameter cannot be determined. This is due to the fact that the Calvo parameter in general is bounded between zero and unity. Given that prices are fixed on average for about 2 months implies that on a quarterly basis, prices change twice within every quarter. This, however, is equivalent to a quarterly flex-price model. Therefore, to analyze monetary policy in Argentina on a quarterly frequency, a flex-price model would be necessary to mimic the Argentine economy. In order to analyze monetary policy in a staggered pricing framework, the model frequency should be no more than monthly.

This result is in stark contrast to the standard results from Taylor (1999) that price changes occur on average once a year and even compared to Bils and Klenow (2004), who find an average duration of fixed prices for a little more than one quarter. These prominent results are, however, for industrialized countries, or to be more specific, the United States. Klenow and Malin (2010) report on micro evidence of price setting from CPI data sets as well as scanner data and show that there are more frequently price changes in Latin

[9] We exclude weekly because it is of less interest for the applications we aim to provide calibration for. Note that $h_q = 1$, $h_m = 1/3$ and $h_d = 1/75$.

America and developing countries in general compared to the United States and the Euro Area. Furthermore, Cavallo (2011) applies the methodology of Bils and Klenow (2004) to daily CPI data for Argentina, Brazil, Chile, and Colombia and generates supportive evidence of a relatively high price changing frequency in these countries compared to industrialized countries. In particular, Cavallo (2011) reports an average duration of fixed prices of 66 days, which is close to the results given in Table 2. Therefore, qualitatively and quantitatively, our high-frequency macroeconomic NKPC procedure generates comparative results to the microeconomic methods of Bils and Klenow (2004). Additionally, Ellis (2009) points out that studying the frequency of price changes at lower frequencies, such as quarterly, tends to overstate the true price stickiness, an argument which is also supported by Abe and Tonogi (2010).

3.5 Robustness

In this subsection, we analyze the robustness of our results with respect to the calibration of the parameters and the choice of the foreign country. First, Table 3 presents the results for alternative calibrations from Escudé (2007) and Galí and Monacelli (2005). Quantitatively and qualitatively, the results are robust to the results from the standard calibration. The estimates for both, the consumption basket based and the food and beverages based CPIs are somewhat larger, but only marginally for the calibration of Galí and Monacelli (2005). Price duration increase by approximately 2 weeks for the consumption based CPI measure and by only one week for the food and beverage based CPI measure. Still, the average of fixed prices is in the close neighborhood of two months. On the other hand, the results from the standard calibration are almost not distinguishable from the case, when the calibration of Escudé (2007) is applied. Summing up, again a quarterly model would need to calibrated as a flex price model to analyze monetary policy or put differently, in order to study monetary policy in a sticky price model a monthly calibration is necessary.

The same outcome holds true if we consider solely the United States as Argentina's trading partner. The upper part of Table 4 displays the results for the case that US data is used to model the foreign country. In general, the point estimates are in line with the former results. In the case Brazil is treated as the only foreign country to Argentina, results remain almost unaltered for the Type II hf-NKPC, but vary considerably for the Type I hf-NKPC. In this case, average price duration spells for both CPI measures drop by almost 3 weeks compared to the multilateral foreign economy.

Nevertheless, the average duration still varies only between 28 and 62 days, which is much less than the variation implied by Galí and Gertler (1999), where variations across estimates are well above 50 days and more.

4 Conclusion

This study aims at mitigating the shortcomings of the estimation of the NKPC arising from small sample bias and structural breaks. To account for such problems, we apply the standard GMM approach to estimating the NKPC to the daily frequency and transform them into pseudo-quarterly equivalences. Applying our method to Argentine data we find the daily Calvo parameter to vary in a very close range around 0.97, which implies averagely fixed prices of approximately 40 days or equivalently one and a half month or half a quarter. These values are well in line with micro evidence for Argentina from Cavallo (2011). Our results have strong implication for the modeling of monetary policy analysis. First, they imply that the frequency of price adjustments has to be calibrated much higher for Argentina compared to the United States or the Euro Area. Second and most important, an average price stickiness of one half quarter means that at a quarterly frequency a flexible price model has to be applied to analyze monetary policy. In the same vein, to analyze monetary policy in a sticky price framework, a monthly model (like the equivalent variation of the standard 3-equation New Keynesian model (NKM) in Franke and Sacht (2010)) seems more appropriate. Our results are not only robust to alternative standard calibrations from the literature, but also on the choice of the CPI definitions, two different proxies for real marginal costs, and alternative country data.

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Appendix

Table 3: Robustness with Respect to Calibration

	Calvo parameter			Average duration of fix prices in...		
	$\theta(h_d)$	$\theta(h_m)$	$\theta(h_q)$	...days	...months	...quarters
Galí and Monacelli (2005)						
Consumption basket:						
Type 1	0.9838 (0.0506)	0.5950	$--^*$	62	2.47	0.82
Type 2	0.9766 (0.0601)	0.4150	$--^*$	43	1.71	0.57
Food and beverages:						
Type 1	0.9789 (0.0294)	0.4725	$--^*$	47	1.90	0.63
Type 2	0.9702 (0.0388)	0.2550	$--^*$	34	1.34	0.45
Escudé (2007)						
Consumption basket:						
Type 1	0.9815 (0.0537)	0.5375	$--^*$	54	2.16	0.72
Type 2	0.9731 (0.0644)	0.3275	$--^*$	37	1.49	0.50
Food and beverages:						
Type 1	0.9764 (0.0322)	0.4100	$--^*$	42	1.69	0.56
Type 2	0.9666 (0.0423)	0.1650	$--^*$	30	1.20	0.40

Note: The daily frequency of price adjustments $\theta(h_d)$ is directly estimated with GMM using the equations (17) and (18). The monthly and quarterly frequencies $\theta(h_m)$ and $\theta(h_q)$ as well as the average duration of fix prices in months and quarters are given by applying the equation (21) respectively. The superscript * implies that the quarterly Calvo parameter cannot be determined (since $\theta(h_q) < 0$), i.e. prices change at least once within every quarter.

Table 4: Robustness with Respect to Foreign Country

	Calvo parameter			Average duration of fix prices in...		
	$\theta\,(h_d)$	$\theta\,(h_m)$	$\theta(h_q)$	...days	...months	...quarters
USA						
Consumption basket:						
Type 1	0.9801	0.5025	$--^*$	50	2.01	0.67
	(0.0550)					
Type 2	0.9712	0.2800	$--^*$	35	1.39	0.46
	(0.0665)					
Food and beverages:						
Type 1	0.9743	0.3575	$--^*$	39	1.56	0.52
	(0.0345)					
Type 2	0.9647	0.1175	$--^*$	28	1.13	0.38
	(0.0441)					
Brazil						
Consumption basket:						
Type 1	0.9737	0.3425	$--^*$	38	1.52	0.51
	(0.0637)					
Type 2	0.9741	0.3525	$--^*$	39	1.54	0.51
	(0.0633)					
Food and beverages:						
Type 1	0.9672	0.1800	$--^*$	30	1.22	0.41
	(0.0417)					
Type 2	0.9676	0.1900	$--^*$	31	1.23	0.41
	(0.0413)					

Note: The daily frequency of price adjustments $\theta(h_d)$ is directly estimated with GMM using the equations (17) and (18). The monthly and quarterly frequencies $\theta(h_m)$ and $\theta(h_q)$ as well as the average duration of fix prices in months and quarters are given by applying the equation (21) respectively. The superscript * implies that the quarterly Calvo parameter cannot be determined (since $\theta(h_q) < 0$), i.e. prices change at least once within every quarter.