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International Competition and Inflation: A New Keynesian Perspective†

By Luca Guerrieri, Christopher Gust, and J. David López-Salido*

We develop and estimate an open economy New Keynesian Phillips Curve (NKPC) in which variable demand elasticities give rise to movements in desired markups in response to changes in competitive pressure from abroad. A parametric restriction yields the standard NKPC under constant elasticity and no role for foreign competition to influence domestic inflation. Foreign competition plays an important role in accounting for the behavior of traded goods price inflation. Foreign competition accounted for more than half of a 4 percentage point decline in domestic goods price inflation in the 1990s. Our results also provide evidence against demand curves with a constant elasticity. (*JEL* E12, E22, E31, F14, F41)

An important question in macroeconomics is the extent to which global factors influence the behavior of aggregate prices. While it is widely recognized that import prices have a direct effect on consumer prices, there is less agreement about the extent to which global factors influence domestic prices. One prominent view is that the prices of US domestic producers mainly depends on domestic variables, with international factors having only a limited impact. Recent work has challenged this view, arguing that the intensifying trend of global economic integration has changed the behavior of inflation, and international considerations have become an important determinant of inflation dynamics.[1]

We address this question in the context of a structural model of inflation in the spirit of Rudiger Dornbusch and Stanley Fischer (1986) and Dornbusch (1987), who

* Guerrieri: Federal Reserve Board, 20th and C Streets NW, Washington, DC 20551 (e-mail: Luca.Guerrieri@frb.gov.); Gust: Federal, Reserve Board, 20th and C Streets NW, Washington, DC 20551 (e-mail: Christopher.Gust@frb.gov.); López-Salido: Federal Reserve Board, 20th and C Streets NW, Washington, DC 20551 (e-mail: David.Lopez-Salido@frb.gov.). We thank two anonymous referees, Giancarlo Corsetti, Chris Erceg, Alejandro Justiniano, Mike Kiley, Sylvain Leduc, Andy Levin, Thomas Lubik, Tommaso Monacelli, Andrea Pescatori, Ananth Ramanarayanan, Argia Sbordone, Cedric Tille, Rob Vigfusson, and Jonathan Wright as well as seminar participants at the Bank of Italy, European Central Bank, European Economic Association 2008 Meetings, Federal Reserve Board, Federal Reserve Bank of Dallas, Federal Reserve Bank of Philadelphia, Federal Reserve Bank of Richmond, Georgetown University, International Monetary Fund, and Universita Bocconi for useful comments and suggestions. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

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[1] For arguments in favor of view that global factors have changed the behavior of inflation, see Claudio Borio and Andrew Filardo (2006) and Kenneth Rogoff (2003). For evidence that the effect has been limited, see Jane Ihrig et al. (2007). Laurence M. Ball (2006) takes an even more extreme position, arguing that there is no effect of foreign variables on US inflation.

emphasized how variations in the desired markups of domestic firms could arise in response to changes in competitive pressures from abroad. These competitiveness effects arise because firms face an elasticity of demand as in Miles S. Kimball (1995), which depends on its price relative to its competitors. As a result, a reduction in the prices of foreign competitors can induce domestic firms to lower their desired markups. We embed these nonconstant elasticity preferences into a short-run model of inflation in which firms only infrequently re-optimize their prices due to the presence of contracts as in Guillermo A. Calvo (1983).

We derive a specification for domestic inflation that depends not only on real marginal cost, but on the prices of imported or foreign goods relative to domestic prices.[2] A parametric restriction on our specification yields the standard New Keynesian Phillips Curve (NKPC) in which the elasticity of demand is constant, and there is no role for competition abroad to directly influence inflation.[3] By comparing the unrestricted and restricted versions of our model, we are able to evaluate the extent to which foreign competition influences the behavior of domestic price setting. In addition, we empirically assess the hypothesis of a constant elasticity of substitution (CES), which is often used by researchers due to its analytical convenience rather than its empirical validity.

Our methodology for estimating inflation closely parallels the present-value approach used in the empirical finance literature. To estimate our model, we use data on the prices of US domestic tradable goods rather than a broader price measure. While this choice represents a departure from most of the empirical literature on inflation, it is motivated by two considerations. First, tradable prices are appropriate given that the theoretical model focuses on the interactions between foreign and domestic producers of tradable products. Second, the behavior of domestic tradable prices should reveal the influence of global factors on the domestic economy more directly relative to broader measures. We view substantiating that domestic tradeable prices are influenced by global factors as an important first step in building a similar case for measures of domestic inflation that include nontradables.

Our results provide evidence that foreign competition has played an important role in explaining the behavior of traded-goods inflation. For instance, we estimate that foreign competition, by reducing the desired markups of domestic producers through lower relative import prices, lowered the annual inflation rate for domestic goods about 2 percentage points in the 1990s. In addition, movements in relative import prices associated with changes in foreign competition accounted for over one-third of the volatility of goods price inflation over our 1983–2006 sample.

Our benchmark estimate for the degree of nominal rigidities is consistent with firms that re-optimize prices, on average, once every three to four quarters.[4] We also find that once we account for the endogenous changes in desired markups, there is a

[2] Our paper is related to a longstanding literature that includes import prices in the estimation of reduced-form Phillips curves such as Robert J. Gordon (1973) and Dornbusch and Fischer (1986). However, our paper differs from these earlier works by providing estimates from a structural model.

[3] Important work estimating the standard NKPC includes Jordi Galí and Mark Gertler (1999); Galí, Gertler, and López-Salido (2001); and Argia M. Sbordone (2002).

[4] This estimate is broadly consistent with the micro evidence of Emi Nakamura and Jon Steinsson (2008), who find a median duration of nonsale prices of 8–11 months using prices for both consumers' and producers' finished goods.

limited role for backward-looking price setting behavior in explaining the dynamics of traded-goods inflation. In contrast, much of the NKPC literature, including Galí and Gertler (1999) and Martin Eichenbaum and Jonas D. M. Fisher (2007), estimate degrees of backward-looking behavior that are significantly different from zero. The difference in our results with these earlier papers reflects our focus on inflation for tradeable goods, which inherits a considerable degree of persistence from movements in relative import prices.

In addition to providing estimates of the importance of foreign competition, we show that the variability in desired markups can be separately identified from changes in markups arising from nominal rigidities in an open economy. As demonstrated by Eichenbaum and Fisher (2007), it is not possible to separately identify the frequency of price re-optimization from the real rigidity associated with changes in desired markups in a one-sector, closed-economy model using aggregate data. To estimate the frequency of price adjustment in closed-economy models, researchers frequently resort to calibrating the parameter governing the variation in the demand elasticity with little empirical guidance. In an open economy, relative import prices are informative about the competitive interaction between foreign and domestic firms, and can shed light on the nature of the demand curve.[5] In this context, our estimates provide evidence against CES demand curves.[6] In particular, we find a large and statistically significant departure from a constant elasticity of substitution. Our estimates for the demand curve are consistent with the calibrated values used in closed-economy contexts by Eichenbaum and Fisher (2007); Gunter Coenen, Andrew T. Levin, and Kai Christoffel (2007); and Michael Dotsey and Robert G. King (2005).[7]

The rest of this paper proceeds as follows. Section I describes our open-economy model with a variable demand elasticity and discusses the issue of identification. Section II and III describe data and empirical methodology. Section IV discusses estimation results, while Section V concludes.

I. An Open-Economy Model with a Variable Demand Elasticity

This section describes the analytical framework that leads to the open-economy NKPC. The framework can be viewed as part of a general equilibrium model which also includes households and the producers of nontradable goods and services. However, in order to help minimize model misspecification, we employ a limited

[5] The closed/open economy distinction is not crucial for identification. It is important that there is an independent source of variation for the price of one sector relative to another, and that pricing decisions are tied together through complementarities.

[6] As emphasized in the literature examining the responsiveness of import prices to exchange rate changes, our estimates of the demand curve imply that pass-through of exchange rate changes to import prices is incomplete. See, Paul R. Bergin and Robert C. Feenstra (2001) and Gust, Sylvain Leduc, and Robert J. Vigfusson (2006) for a discussion, and Giancarlo Corsetti, Luca Dedola, and Leduc (2008), for example, for an alternative model of incomplete pass-through.

[7] Recent work using disaggregated data to examine Kimball-type demand curves yields ambiguous results regarding their empirical validity. Using disaggregated data on US consumer prices and indirect inference from a calibrated model, Peter J. Klenow and Jonathan L. Willis (2006) argue that reconciling the Kimball demand curve with large observed changes in relative prices requires large idiosyncratic productivity shocks. In contrast, Maarten Dossche, Freddy Heylen, and Dirk Van den Poel (2006), using supermarket scanner data on prices and quantities for similar goods in similar locations, find evidence in support of the Kimball aggregator.

information approach in estimating traded goods inflation, and only describe the part of the model that is relevant for the estimation approach.

Before describing this setup, it is useful to present the specification of the NKPC. Under the assumption of Calvo-style staggered price contracts and demand curves that allow for pricing complementarities between home and foreign producers, we show

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa[(1 - \Psi)\hat{s}_t + \Psi\phi\hat{p}_{Mt}], \tag{1}$$

where $\hat{\pi}_t$ is the inflation rate for domestic producer prices, $\hat{s}_t$ is real marginal cost, and $\hat{p}_{Mt}$ represents import prices relative to domestic prices with these variables all expressed in logarithmic deviation from steady state. The response of inflation to changes in marginal cost is expressed as the product of two coefficients: κ, which depends on the degree of nominal rigidity, and Ψ, which governs the variations in desired markups associated with competition from other firms. Because a domestic firm will vary its desired markup in response to price changes of its foreign competitors, Ψ also influences how changes in relative import prices affect domestic prices, while the parameter ϕ is influenced by other structural factors such as the degree of trade openness and the elasticity of substitution between home and foreign goods. We use equation (1) as the basis for our empirical investigation. We now turn to the main ingredients of the model necessary to derive it and provide a structural interpretation to the coefficients.

A. *Final Good Producers*

At time t, an aggregate final good, A_t, is produced by perfectly competitive firms. The representative firm combines a continuum of intermediate goods produced at home and another continuum produced abroad. The firm chooses domestically-produced goods, $A_{Dt}(i)$, $i \in [0,1]$, imported goods, $A_{Mt}(i)$, $i \in [0,1]$, and A_t to maximize profits:

$$\max_{A_t, A_{Dt}(i), A_{Mt}(i)} P_{At}A_t - \left[\int_0^1 P_{Dt}(i)A_{Dt}(i)\,di - \int_0^1 P_{Mt}(i)A_{Mt}(i)\,di\right], \tag{2}$$

subject to $\int_0^1 D\left(\frac{A_{Dt}(i)}{A_t}, \frac{A_{Mt}(i)}{A_t}\right)di \geq 1.$

For $\int_0^1 D\left(\frac{A_{Dt}(i)}{A_t}, \frac{A_{Mt}(i)}{A_t}\right)di$, we adopt the aggregator used by Gust, Leduc, and Vigfusson (2006), who extend the one discussed in Dotsey and King (2005) to an international environment. This aggregator is given by

$$\int_0^1 D\left(\frac{A_{Dt}(i)}{A_t}, \frac{A_{Mt}(i)}{A_t}\right)di = \left[V_{Dt}^{1/\rho} + V_{Mt}^{1/\rho}\right]^\rho - \frac{1}{(1-\nu)\gamma_t} + 1. \tag{3}$$

In turn, V_{Dt} is an aggregator of domestically produced goods given by

$$V_{Dt} = \int_0^1 \frac{(1-\omega)^\rho}{(1-\nu)\gamma_t} \left[\frac{1-\nu}{1-\omega} \frac{A_{Dt}(i)}{A_t} + \nu\right]^{\gamma_t} di, \tag{4}$$

and V_{Mt} is an aggregator of imported goods given by

$$V_{Mt} = \int_0^1 \frac{\omega^\rho}{(1-\nu)\gamma_t} \left[\frac{(1-\nu)}{\omega} \frac{A_{Mt}(i)}{A_t} + \nu\right]^{\gamma_t} di. \tag{5}$$

In the equation above, the parameter ρ influences the substitutability between domestic and foreign goods. The share parameter ω is related to the degree of home bias in preferences and can be thought of as indexing the degree of trade openness.

Our estimation strategy explicitly requires us to model an error to our structural equation for inflation. We let γ_t be an exogenous shock influencing the elasticity of substitution between varieties produced within a given country, which, as we discuss later, introduces exogenous variations in markups and hence in aggregate inflation. We specify that γ_t evolves according to

$$\gamma_t = \gamma \exp(\epsilon_{\gamma t}), \tag{6}$$

where $\epsilon_{\gamma t}$ is an identically and independently distributed process with zero-mean and standard deviation, σ_γ. Later, we verify that once you take into account endogenous variations of the markup, this error is in fact white noise and thus makes no contribution to inflation persistence. In contrast, recent empirical applications such as Peter N. Ireland (2004) have generally assumed that the exogenous movements in the markup are serially autocorrelated.

To understand our aggregator, it is useful to abstract from the identically and independently distributed markup shock. In that case, when $\nu > 0$ and $\gamma_t = \gamma$, the elasticity of demand is variable (VES) and the (absolute value of the) demand elasticity can be expressed as an increasing function of a firm's relative price. When $\nu = 0$ and $\gamma_t = \gamma$, the demand aggregator has a constant elasticity of substitution (CES) and can be thought of as the combination of Dixit-Stiglitz and Armington aggregators. In particular, in this case, our aggregator can be rewritten as

$$A_t = \left[(1-\omega) A_{Dt}^{\frac{\gamma}{\rho}} + \omega A_{Mt}^{\frac{\gamma}{\rho}}\right]^{\frac{\rho}{\gamma}},$$

where $A_{Dt} = \left(\int_0^1 A_{Dt}(i)^\gamma di\right)^{\frac{1}{\gamma}}$ and $A_{Mt} = \left(\int_0^1 A_{Mt}(i)^\gamma di\right)^{\frac{1}{\gamma}}$.

As shown in the Appendix, profit maximization by the representative final good producer implies that its demand for domestic good i is given by

$$A_{Dt}(i) = (1-\omega)\left[\frac{1}{1-\nu}\left(\frac{P_{Dt}(i)}{P_{Dt}}\right)^{\frac{1}{\gamma_t - 1}} \left(\frac{P_{Dt}}{P_{Ft}}\right)^{\frac{\rho}{\gamma_t - \rho}} - \frac{\nu}{1-\nu}\right] A_t. \tag{7}$$

In these demand curves, P_{Mt} and P_{Dt} are price indices of domestic and imported goods given by

$$(8) \qquad P_{Dt} = \left(\int_0^1 P_{Dt}(i)^{\frac{\gamma_t}{\gamma_t - 1}} \, di\right)^{\gamma_t - \frac{1}{\gamma_t}} \quad \text{and} \quad P_{Mt} = \left(\int_0^1 P_{Mt}(i)^{\frac{\gamma_t}{\gamma_t - 1}} \, di\right)^{\frac{\gamma_t - 1}{\gamma_t}},$$

while P_{Ft} is a price index consisting of all the prices of a firm's competitors:

$$(9) \qquad P_{Ft} = \left[(1 - \omega)P_{Dt}^{\frac{\gamma_t}{\gamma_t - \rho}} + \omega P_{Mt}^{\frac{\gamma_t}{\gamma_t - \rho}}\right]^{\frac{\gamma_t - \rho}{\gamma_t}}.$$

As in Dotsey and King (2005), when $\nu \neq 0$ in equation (7), these demand curves have a linear term which implies that the elasticity of demand depends on a firm's price relative to the prices of its competitors, P_{Ft}.

B. *Intermediate Good Producers*

Intermediate good i is produced by a monopolistically competitive firm, whose technology is Cobb-Douglas over capital and labor. Intermediate goods producers face perfectly competitive factor input markets within a country. Capital and labor are assumed to be immobile across countries, but completely mobile within a country. Thus, within a country, all firms have the same marginal cost, MC_t.

Intermediate goods producers sell their products to the consumption goods distributors, and we assume that markets are segmented so that firms can charge different prices at home and abroad (i.e., price to market). The domestic price is determined according to Calvo-style contracts. In particular, firm i faces a constant probability $1 - \theta$ of being able to re-optimize its price. This probability is assumed to be independent across time, firms, and countries. If firm i cannot re-optimize its price at time t, the firm resets its price based on lagged inflation as in Lawrence J. Christiano, Eichenbaum, and Charles L. Evans (2005). In particular, $P_{Dt}(i) = \pi^{1-\delta_D} \pi_{t-1}^{\delta_D} P_{Dt-1}(i)$, where $\pi_{t-1} = P_{Dt}/P_{Dt-1}$, and the parameter $0 \leq \delta_D \leq 1$ captures the degree of indexation to past inflation. In this specification $\delta_D = 0$ corresponds to indexation to steady state inflation (π), and $\delta_D = 1$ implies full indexation to past inflation. When firm i can re-optimize in period t, it maximizes

$$(10) \qquad E_t \sum_{j=0}^{\infty} \xi_{t+j} \theta^j \, [I_{Dt+j} \, P_{Dt}(i) - MC_{t+j}] AD_{t+j}(i),$$

taking MC_{t+j}, its demand schedule, and the indexing scheme, $I_{Dt+j} = \Pi_{h=1}^{j} \pi^{1-\delta_D} \pi_{t+h-1}^{\delta_D}$ as given. In equation (10), ξ_{t+j} is the stochastic discount factor with steady state value, $\beta \in (0, 1)$, and E_t denotes the conditional expectations operator at date t. The first-order condition from this problem is

$$(11) \qquad E_t \sum_{j=0}^{\infty} \xi_{t+j} \, \theta^j \left[1 - \left(1 - \frac{MC_{t+j}}{I_{Dt+j} P_{Dt}(i)}\right) \epsilon_{t+j}(i)\right] A_{Dt+j}(i) = 0,$$

where the elasticity of demand for good i in the domestic market is

$$\epsilon_t(i) = \frac{1}{1-\gamma_t}\left[1 - \nu\left(\frac{P_{Dt}(i)}{P_{Dt}}\right)^{\frac{1}{1-\gamma_t}}\left(\frac{P_{Dt}}{P_{Ft}}\right)^{\frac{\rho}{\rho-\gamma_t}}\right]^{-1}. \tag{12}$$

This elasticity results in a time-varying markup of the form

$$\mu_t(i) = \frac{\epsilon_t(i)}{\epsilon_t(i)-1} = \left[\gamma_t + \nu(1-\gamma_t)p_{Dt}(i)^{\frac{1}{1-\gamma_t}}\, p_{Ft}^{\frac{\rho}{\gamma_t-\rho}}\right]^{-1}, \tag{13}$$

where the lower-case variables denote relative prices (i.e., $p_{Dt}(i) = P_{Dt}(i)/P_{Dt}$ and $p_{Ft} = P_{Ft}/P_{Dt}$).

To understand variations in the desired markup (i.e., the markup in the absence of price rigidities and the exogenous shock γ_t), it is useful to log-linearize equation (13) around a steady state in which relative prices are equal to one and write it as

$$\hat{\mu}_t(i) = \hat{\mu}_{Dt}(i) - \varphi_\mu \hat{\gamma}_t, \tag{14}$$

where $\hat{\mu}_{Dt}(i)$ is the log-linearized desired markup and $\varphi_\mu = (\mu - 1)\gamma/(1-\gamma)$. The desired markup is given by

$$\hat{\mu}_{Dt}(i) = -\left[\frac{\partial\epsilon(i)}{\partial p_D(i)}\,\frac{1}{\epsilon}\right](\mu-1)\hat{p}_{Dt}(i) + \left[\frac{\partial\epsilon(i)}{\partial p_M}\,\frac{1}{\epsilon}\right](\mu-1)\hat{p}_{Mt}. \tag{15}$$

The steady-state (gross) markup of an intermediate good producer is given by

$$\mu = \frac{1}{\gamma + (1-\gamma)\nu} > 1, \tag{16}$$

and $\epsilon = 1/(1-\gamma)(1-\nu)$ is the steady-state demand elasticity.

According to equation (15), there are two sources of variations in desired markups. The first reflects variations arising from deviations in a firm's price relative to the prices of its domestic competitors. Variations in desired markups arising from this source depend on $(\partial\epsilon(i)/\partial p_D(i))\ 1/\epsilon = \nu\epsilon$, which is the elasticity of the elasticity with respect to a firm's relative price. For $\nu > 0$, this elasticity measures how much $\epsilon_t(i)$ increases when a firm raises its price above the prices of its domestic competitors. In that case, a firm will lower its desired markup so that its notional price does not deviate too far from those of its domestic competitors. If $\nu = 0$, then the demand curves are CES absent the markup shock, and $(\partial\epsilon(i)/\partial p_D(i))\ 1/\epsilon = 0$.

The second source of variation in a firm's desired markup arises from foreign competition. This source depends on $(\partial\epsilon(i)/\partial p_M)\ 1/\epsilon = \nu\epsilon_A\omega$, where

$$\epsilon_A = \frac{\rho}{(\rho-\gamma)(1-\nu)} > 0 \tag{17}$$

is the elasticity of substitution between home and foreign goods. This elasticity of the elasticity, $(\partial \epsilon(i)/\partial p_M)\ 1/\epsilon$, measures how much $\epsilon_t(i)$ rises when relative import prices fall. In that case, a firm faces stiffer competition from abroad and will lower its desired markup. The importance of foreign competitiveness on the desired markups of domestic firms depends on the degree of trade openness (ω) and the elasticity of substitution between home and foreign goods. International competition has a larger influence on desired markups when an economy is more open, or its goods are closer substitutes with foreign goods. For $\nu = 0$, the CES case, there is no effect of foreign competitiveness on domestic markups and $(\partial \epsilon(i)/\partial p_M)\ 1/\epsilon = 0$.

Substituting out $(\partial \epsilon(i)/\partial p_D(i))\ 1/\epsilon$ and $(\partial \epsilon(i)/\partial p_M)\ 1/\epsilon$, the desired markup can be expressed as

$$\hat{\mu}_{Dt}(i) = -\frac{\Psi}{1-\Psi}\hat{p}_{Dt}(i) + \frac{\Psi}{1-\Psi}\frac{\epsilon_A}{\epsilon}\omega \hat{p}_{Mt}, \tag{18}$$

where the parameter Ψ reflects the variations in the desired markup associated with competition from other firms and is given by

$$\Psi = \frac{(\mu-1)\dfrac{\partial \epsilon(i)}{\partial p_D(i)}\dfrac{1}{\epsilon}}{1 + (\mu-1)\dfrac{\partial \epsilon(i)}{\partial p_D(i)}\dfrac{1}{\epsilon}} = \frac{\nu\mu}{1+\nu\mu}. \tag{19}$$

In the empirical work, we focus on estimating Ψ while calibrating the values of μ and ϵ_A. These three parameters uniquely determine the demand curve parameters discussed earlier—ρ, γ, and ν—via equations (16), (17), and (19).

C. *Inflation Dynamics*

To understand the role of variations in desired markups for inflation, we log-linearize the firm's first-order condition for price re-optimization, equation (11). As detailed in the Appendix, after some algebraic manipulation, a first-order approximation to this equation yields

$$\hat{\pi}_t - \delta_D \hat{\pi}_{t-1} = \beta E_t[\hat{\pi}_{t+1} - \delta_D \hat{\pi}_t] + \kappa\left[(1-\Psi)\hat{s}_t + \Psi\omega\frac{\epsilon_A}{\epsilon}\hat{p}_{Mt} + \varphi\hat{\gamma}_t\right], \tag{20}$$

where $\kappa = (1-\beta\theta)(1-\theta)/\theta$ and $\hat{\pi}_t$ is domestic price inflation expressed as a log deviation from steady state, $\hat{s}_t$ represents real marginal cost (defined using P_{Dt}), and the composite parameter, φ, influences the sensitivity of inflation to exogenous variations in the markup and is given by $\varphi = 2\Psi - 1$.

Since we allow for partial indexation to lagged inflation, current inflation is affected by inflation in the previous period. Similar to a standard NKPC (e.g., Galí and Gertler 1999), the Calvo price setting parameter, θ, affects the responsiveness of inflation to real marginal cost through its effect on κ. However, equation (20) differs from the standard specification, since relative import prices also affect inflation. In an open economy, a domestic firm must take into account the prices of its foreign competitors on its desired markup.[8] If foreign goods become relatively less expensive, then domestic firms will respond by lowering their desired markups in order to maintain a competitive price. Hence, this puts downward pressure on π_t.

The importance of this foreign competitiveness effect on domestic inflation depends on the degree of trade openness (ω), the import price elasticity (ϵ_A), and Ψ. We use Ψ to gauge the extent of the real rigidity associated with pricing complementarities between firms. A higher value of Ψ reduces the sensitivity of inflation to real marginal cost and raises the sensitivity of inflation to relative import prices.

Identifying the Real Rigidity.—Equation (20) nests two important cases. With $\Psi = 0$, the CES case, there is no direct effect of international competition on domestic prices. Equation (20) is observationally equivalent to the specification estimated by Galí and Gertler (1999), among others. Another interesting case is the one considered by Eichenbaum and Fisher (2007) in which $\omega = 0$. In this case, the domestic economy does not import foreign goods, and a domestic firm, while willing to vary its desired markup in response to domestic competition, need not be concerned with foreign competition. Accordingly, relative import prices do not affect domestic price inflation.

As discussed by Eichenbaum and Fisher (2007), one cannot separately identify Ψ and θ in a one-sector, closed economy (i.e., $\omega = 0$) using aggregate data. As a result, many researchers opt to calibrate the value of Ψ with little empirical guidance. However, when $\omega > 0$, relative import prices are informative about the extent to which firms vary their desired markups, and it is clear from equation (20) that it is possible to jointly identify both Ψ and θ.[9]

Building on the work of Bergin and Feenstra (2001), Hafedh Bouakez (2005) examines the ability of a sticky price model with a Kimball aggregator to explain the persistence of the real exchange rate rather than focusing on the effects of foreign competition. Unfortunately, Bouakez (2005) cannot separately identify variations in desired markups from variations in markups associated with nominal rigidities.[10]

[8] Our specification has some similarities to Marco Vega and Diego Winkelried (2005). Our analysis is different from theirs, mainly because they do not explore the empirical implications of their model. Instead, we focus on the empirical relevance of foreign competition on domestic inflation, paying special attention to the issue of identification of real and nominal rigidities. Also, Sbordone (2007) analyzes how the entry of new competitors affects the slope of the NKPC in a closed economy context using the preferences of Dotsey and King (2005).

[9] Coenen, Levin, and Christoffel (2007) alter the standard Calvo framework and show how one can separately identify real and nominal rigidities in a closed-economy framework in which there are nominal pricing contracts of different durations. Their approach exploits the more complex dynamics between inflation and real marginal cost induced by their contracting structure, and they use simulated methods of moments to estimate the parameters. Instead, we use the baseline Calvo model and exploit variation in relative import prices to provide information regarding the nature of demand curves and endogenous changes in desired markups.

[10] Our aggregator also has the attractive feature of implying similar behavior for the desired prices of international goods as the game-theoretic models of Andrew Atkeson and Ariel Burstein (2008). See the Appendix of Gust, Leduc, and Vigfusson (2006) for a discussion.

D. *Firm-Specific Capital*

We now extend the analysis to incorporate firm-specific capital. To do so, we assume that the production function for intermediate good i is given by

$$Y_t(i) \;=\; \overline{K}^{\alpha}\big(Z_t L_t(i)\big)^{1-\alpha}, \tag{21}$$

where $L_t(i)$ is a firm's demand for labor and Z_t is a common technological factor. Finally, $\overline{K}$ denotes each firm's fixed stock of capital. As discussed in Coenen, Levin, and Christoffel (2007), the firm-specific level of capital can be interpreted more broadly as production factors that remain fixed in the short run (such as land and overhead labor), while $L_t(i)$ can be interpreted as those factors which are variable in the short run.

Under these assumptions, firm i's marginal cost is given by

$$MC_t(i) \;=\; \frac{1}{1-\alpha}\,\frac{W_t}{QZ_t}\,Y_t(i)^{\frac{\alpha}{1-\alpha}}, \tag{22}$$

where $Q = \overline{K}^{\frac{\alpha}{1-\alpha}}$ and $\alpha/(1-\alpha) > 0$ can be interpreted as the short-run elasticity of the firm's marginal cost to output. Because capital specificity implies that the firm's marginal cost is an increasing function of its output, it acts as another source of real rigidity. In particular, following an increase in demand, a firm with the opportunity to raise its price will have a weaker incentive to do so, since the fall in the relative demand for its good reduces its marginal cost.

In the benchmark economy, a domestic producer may set different prices at home and abroad, and its pricing decision in its home market is completely independent of its pricing decision in its foreign market. With firm-specific capital, this is no longer true. A firm's export price affects a firm's domestic price through its effect on the demand for its product, $Y_t(i)$, which alters its marginal cost. To keep the analysis tractable, we abstract from these effects and assume that the domestic firms that compete with foreign firms in the domestic market are distinct from those firms which export.

With a firm's production equal to its domestic demand $\big($i.e., $Y_t(i) = A_{Dt}(i)\ \forall i\big)$, the first-order condition for a firm that re-optimizes its price at date t is

$$E_t \sum_{j=0}^{\infty} \xi_{t+j}\theta^j \left[1 \;-\; \left(1 \;-\; \frac{MC_{t+j}(i)}{V_{Dt+j}\,P_{Dt}(i)}\right)\epsilon_{Dt+j}(i)\right] A_{Dt+j}(i) \;=\; 0. \tag{23}$$

The log-linearized expression for domestic inflation in this case is given by

$$\hat{\pi}_t \;-\; \delta_D\hat{\pi}_{t-1} \;=\; \beta E_t[\hat{\pi}_{t+1} \;-\; \delta_D\hat{\pi}_t] \;+\; \kappa_D\Big[(1-\Psi)\hat{s}_t \;+\; \Psi\omega\,\frac{\epsilon_A}{\epsilon}\,\hat{p}_{Mt} \;+\; \varphi\hat{\gamma}_t\Big], \tag{24}$$

where $\kappa_D = \kappa/\big(1 + (\epsilon\alpha/(1-\alpha))(1-\Psi)\big)$, and Ψ and κ are defined as before. Comparing equation (24) with equation (20), it is clear that capital specificity does

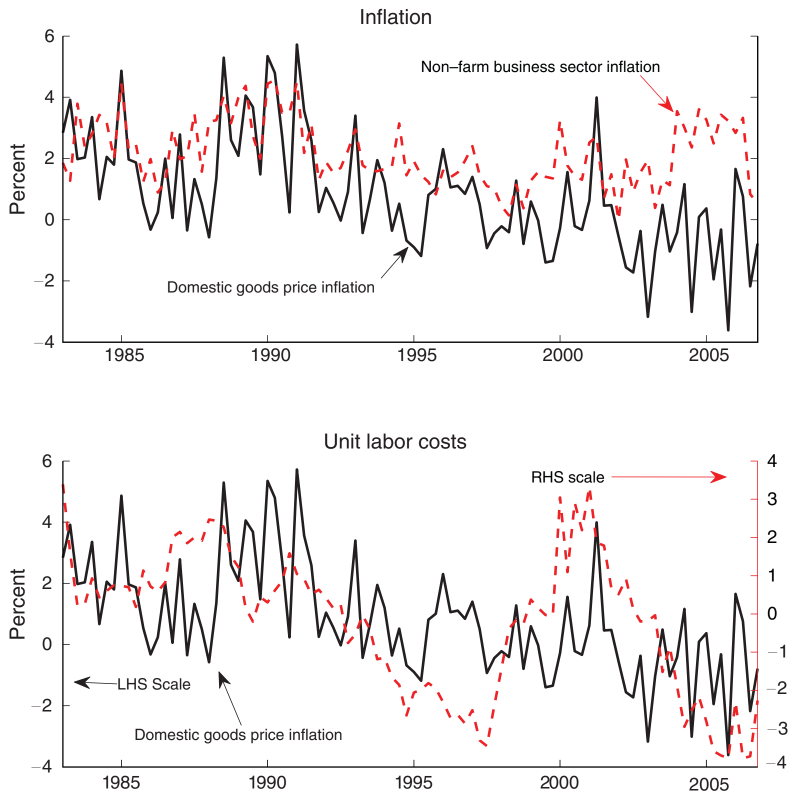

FIGURE 1. TRADABLE GOODS INFLATION AND UNIT LABOR COSTS, 1983–2006

not alter the form of the NKPC but lowers the reduced-form slope coefficient since $\kappa_D < \kappa$ with $\alpha > 0$. In the empirical analysis, we calibrate α and estimate θ and Ψ.

II. Data

For the benchmark estimates, we use quarterly data on inflation, marginal cost, and relative import prices from 1983–2006. The focus on this sample period helps abstract from changes in monetary policy regimes. Since the theoretical analysis applies to the prices of tradables, we construct an inflation measure based on goods prices (from NIPA Table 1.2.4). We also net out the prices of exported goods, reflecting that prices at home and abroad can differ.[11] The upper panel of Figure 1 plots goods inflation and inflation in the nonfarm business sector from 1983–2006. The two series are positively correlated with each other (the correlation is 0.5). Goods price inflation, however, has been lower, on average, than overall inflation, as well as more volatile, particularly over the past 15 years.

[11] We construct a Laspeyres index for domestic goods prices by excluding the index for export prices from the overall index for goods prices. See NIPA table 4.2.4.

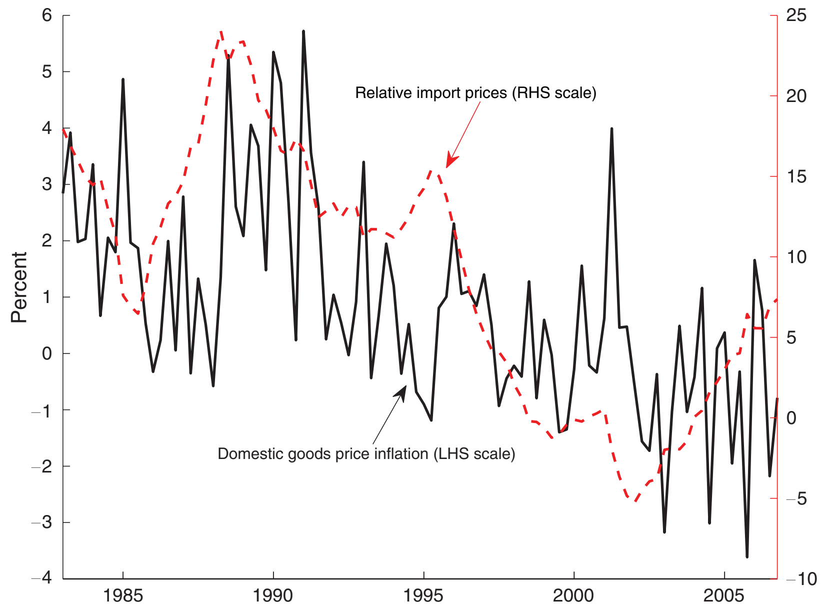

Figure 2. Relative Import Prices and the Import Share, 1983–2006

To measure real marginal cost, s_t, we use data on the labor share in the nonfarm business sector defined as nominal labor compensation divided by nominal output. This measure is the standard one used by Galí and Gertler (1999), Sbordone (2002), and Eichenbaum and Fisher (2007) among others.[12] The lower panel of Figure 1 plots the labor share in the nonfarm business sector along with GDP goods inflation. The labor share declined throughout the first half of the 1990s, rose noticeably at the end of the 1990s, and then dropped sharply from 2001 to 2005.

We use the National Income and Product Accounts (NIPA) price deflator for non-oil imported goods and define relative import prices by dividing this measure by the deflator for domestic goods prices. We exclude oil prices, because oil is used as an intermediate input and because oil's share of imports is much larger than its share in domestic production. Later, as sensitivity analysis, we use an alternative import prices series that includes only final goods, as in the theoretical model. However, this alternative excludes some final goods, such as automobiles, that are part of the basket of domestically produced goods.

The relative price of non-oil imports is shown in Figure 2 along with domestic goods inflation. Relative import prices are positively correlated with goods inflation, rising and falling with inflation in the 1980s and moving toward a lower level in the 1990s before trending upward over the past five years.

[12] A measure that corresponded more closely to costs in the tradable sector is the labor share for the manufacturing sector, but it is only available on an annual basis beginning in 1986.

III. Empirical Methodology

Our methodology closely parallels the present-value approach used in the empirical finance literature.[13] In particular, we rewrite equation (20) as a relationship between inflation and the expected discounted value of the future values of real marginal cost and relative import prices,

$$(25)\quad \hat{\pi}_t = \delta_D \hat{\pi}_{t-1} + \kappa_D \sum_{k=0}^{\infty} \beta^k E_t\Big[(1-\Psi)\hat{s}_{t+k} + \Psi\omega \frac{\epsilon_A}{\epsilon}\hat{p}_{Mt+k} + \varphi\hat{\gamma}_{t+k}\Big],$$

where $\kappa_D = \kappa$ if capital is not firm-specific. To estimate the parameters of interest using (25), we need forecasts of real marginal cost and relative import prices, obtained through a vector autoregression (VAR). Defining X_t as a vector of variables that includes s_t and p_{Mt}, the VAR in companion form can be written as

$$(26)\quad X_t = AX_{t-1} + u_t,$$

where A is a matrix of VAR coefficients, and u_t is a vector of independently and identically distributed innovations that may be correlated with each other. With the VAR expressed in this way, we compute the forecasts of X_t using the relationship $E_t\{X_{t+k}\} = A^k X_t$.

It is important to recognize that both real marginal cost and relative import prices are still endogenously determined by equations (25) and (26), because the elements of the error vector, u_t, are allowed to be contemporaneously correlated with each other and with the markup shock in equation (25). The main appeal of our limited information approach relative to full information estimation of a DGE model is that we do not need to make strong assumptions about the auxiliary variables in X_t.[14] Such assumptions, if unwarranted, can lead to inconsistent estimates of δ_D, θ, and Ψ. In the context of an open economy, these misspecification problems can be pernicious, in part, because modeling the determination of the exchange rate is a particularly challenging endeavor.[15] In our context, with a full information approach, relative import prices would depend on the particular assumptions regarding exchange rate determination. By contrast, the limited-information approach allows us to leave the determination of the exchange rate unspecified. Still, observed movements in the exchange rate permeate the estimated model through their effects on relative import prices and marginal costs.

For the benchmark specification of the VAR, we include only measures of real unit labor costs and relative import prices in X_t. Furthermore, we used the Box-Jenkins methodology to test down from an unrestricted VAR with longer lag length.

[13] For a summary of this literature, see chapter 7 of John Y. Campbell, Andrew W. Lo, and A. Craig MacKinlay (1996). For an early application of this approach to inflation dynamics, see Sbordone (2002).

[14] Our use of the term "limited information approach" is the same as in Adrian R. Pagan (1979). He defines the limited information approach as estimating an Euler equation jointly with a statistical model for the endogenous right-hand side variables.

[15] For a comparison between the limited and full information approaches in an open economy setting, see Martin Fukac and Adrian Pagan (2008). They conclude that the full information approach leads to biased estimates in part due to misspecification associated with the determination of the exchange rate.

We choose an AR(1) process for real unit labor costs and an AR(2) process for relative import prices. Later, we conduct sensitivity analysis in which we allow for feedback between unit labor costs and import prices in the VAR. For our benchmark specification of the VAR, the equation for inflation that we estimate is

$$(27) \quad \hat{\pi}_t = \delta_D \hat{\pi}_{t-1} + \kappa_D \left[\frac{1-\Psi}{1-\beta\rho_s} \hat{s}_t + \omega \frac{\epsilon_A}{\epsilon} \frac{\Psi(1 + \beta\rho_{M2} L)}{1 - \beta\rho_{M1} - \beta^2 \rho_{M2}} \hat{p}_{Mt} \right] + \epsilon_{\pi t},$$

where L is the lag operator, ρ_s is the autoregressive coefficient for unit labor costs, ρ_{M1} and ρ_{M2} are the autoregressive coefficients for import prices. We jointly estimate the VAR, equation (26), along with the process for inflation, equation (27).

The error term satisfies $\epsilon_{\pi t} = \kappa\varphi\hat{\gamma}_t$ and thus reflects the presence of *independently and identically distributed* shocks to the markup. Since the exogenous variation in markups may be correlated with unit labor costs and import prices, we use lagged variables as instruments. Our benchmark set of instruments includes two lags of traded goods inflation, one lag of real unit labor costs, and one lag of relative import prices. The choice of this instruments set was guided by the Cragg-Donald g_{min} statistic, which led to the exclusion of longer lags of the endogenous variables. As robustness, we also use maximum likelihood estimation as an alternative to generalized method of moments (GMM).

Identification and Calibration.—We estimate δ, θ, Ψ, as well as A, the coefficients from the VAR used to forecast unit labor costs and import prices (for our benchmark specification, the relevant elements of A are ρ_s, ρ_{M1}, and ρ_{M2}). We calibrate μ, ω, and ϵ_A. Given uncertainty about the values of these parameters, we report results for alternative calibrations in our sensitivity analysis. Throughout our analysis, we set $\beta = 0.99$.

For our benchmark calibration, we choose $\mu = 1.2$, which is at the midpoint of the estimates surveyed by Julio J. Rotemberg and Michael Woodford (1995), but higher than the estimate of Susanto Basu and John G. Fernald (1997). This value of μ implies $\epsilon = 6$. We choose ϵ_A, the elasticity of substitution between home and foreign goods, to be 1.5. This estimate is toward the higher end of estimates using macroeconomic data, which are typically below unity in the short run and near unity in the long run (e.g., Peter Hooper, Karen Johnson, and Jaime Marquez 2000). Nevertheless, estimates of this elasticity following a tariff change are typically higher.[16] For the version of the model with firm-specific capital, following Coenen, Levin, and Christoffel (2007), we set $\alpha = 0.4$.

We choose ω based on the ratio of non-oil imported goods to total goods production. Because of a secular rise in the share of imports, it is difficult to determine an appropriate value for ω, which in our model corresponds to the steady-state import share. For our benchmark calibration, we choose $\omega = 0.26$, which is the sample

[16] For a discussion of the macro estimates and estimates after trade liberalizations, see Kim Ruhl (2005).

Table 1—Estimates of Open Economy Calvo Model
(*Firm-specific capital* 1983:Q1–2006:Q4)[a,b]

	VES with indexation	VES without indexation	CES with indexation	CES without indexation
θ	0.75	0.73	0.79	0.77
	(0.04)	(0.04)	(0.04)	(0.04)
Ψ	0.78	0.78	0	0
	(0.13)	(0.13)	—	—
δ_D	0.14	0	0.35	0
	(0.09)	—	(0.09)	—
$\frac{\sigma_{\pi^F}}{\sigma_\pi}$	0.73	0.77	0.37	0.28
$\frac{\sigma_\pi^{p_m}}{\sigma_\pi}$	0.36	0.49	0.00	0.00
Q-Statistic(1)	0.08	2.95	0.44	11.95
	[0.77]	[0.09]	[0.51]	[0.00]
Q-Statistic(4)	3.47	7.56	11.34	44.50
	[0.48]	[0.11]	[0.02]	[0.00]
g_{min}	0.80	1.46	225.53	251.41
(*Capital not firm specific*)[c]				
θ	0.81	0.80	0.90	0.89
	(0.04)	(0.04)	(0.02)	(0.02)

[a] Standard errors are reported in parentheses. A dash in lieu of a standard error indicates that we restricted the corresponding parameter. Q-statistic refers to the Ljung-Box test for serial correlation of $\epsilon\pi t$ at lags 1 and 4. Probability values of Q-statistics are reported in brackets. $\sigma_{\pi F}/\sigma\pi$ refers to the ratio of the volatility of predicted inflation to the volatility of actual inflation, and $\sigma_{\pi^{p_m}}/\sigma\pi$ refers to the contribution of the relative import price to inflation volatility.

[b] The estimated inflation equation is

$$\hat{\pi}_t = \delta_D \hat{\pi}_{t-1} + \kappa_D \left[\frac{1-\Psi}{1-\beta\rho_s} \hat{s}_t + \omega \frac{\epsilon_A}{\epsilon} \frac{\Psi(1 + \beta\rho_{M2} L)}{1 - \beta\rho_{M1} - \beta^2 \rho_{M2}} \hat{p}_{Mt} \right] + \epsilon_{\pi t},$$

where $\kappa_D = \dfrac{(1-\beta\theta)(1-\theta)}{\theta[1 + \epsilon \frac{1-\alpha}{\alpha}(1-\Psi)]}$.

[c] When capital is not firm-specific $\kappa_D = \kappa = \dfrac{(1-\beta\theta)(1-\theta)}{\theta}$.

average for the 1983:Q1–2006:Q4 period. Later, as sensitivity analysis, we consider a version of the model which allows for a trending import share.

IV. Estimation Results

The top part of Table 1 reports our estimates of θ, Ψ, and δ_D for the version of the model in which capital is firm-specific.[17] The bottom part of the table reports the estimates of θ for the version of the model in which capital moves freely across firms (all the other statistics in the table are unaffected by the mobility of capital).[18] With firm-specific capital, the second column of Table 1 shows that the estimate of θ

[17] Estimates of the auxiliary VAR are provided in the working paper version, Guerrieri, Gust, and López-Salido (2008).

[18] As discussed earlier, θ and α are not separately identified.

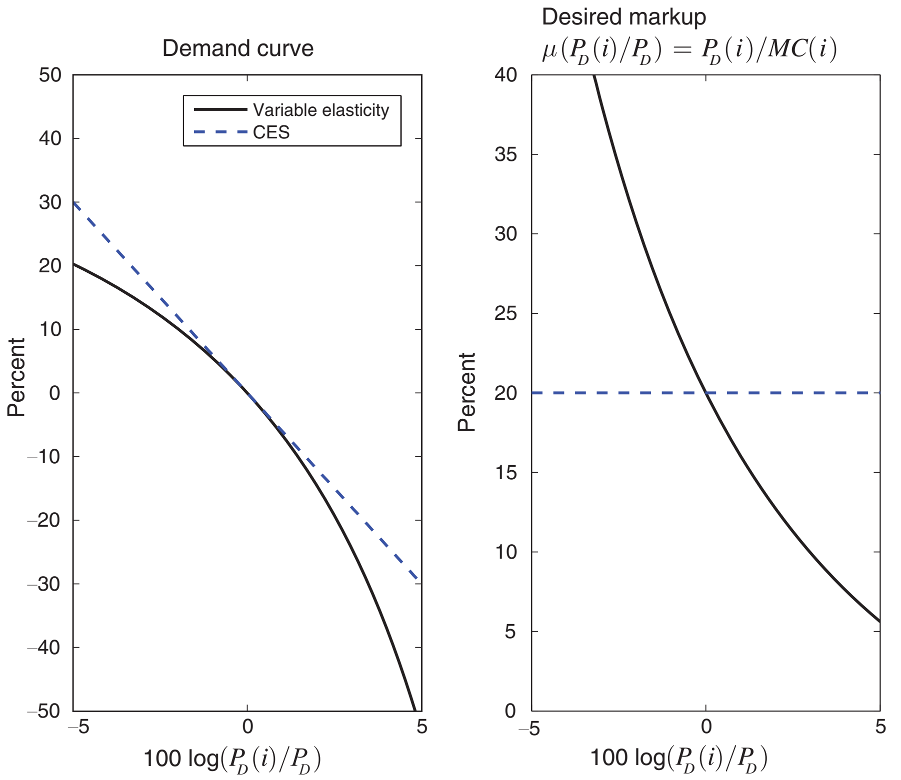

Figure 3. Properties of Estimated Demand Curve

is 0.75 for the model with a variable elasticity (VES), which implies that a firm, on average, re-optimizes its price every four quarters. In contrast, without capital specificity, $\theta = 0.81$, implying an average contract duration of over five quarters. Since our estimate of θ is the only difference in results between these two specifications, and it is reasonable to believe that some production factors are firm-specific, we shall focus exclusively on the model in which capital is firm-specific. Table 1 shows that our estimate of Ψ implies a demand elasticity that is far from constant, as the estimated value of Ψ is 0.78. The asymptotic standard errors reported in the table imply that the estimate of Ψ is significantly different from 0, thus rejecting the CES model.[19]

To tie back our point estimate of Ψ to an individual firm's demand, the upper left panel of Figure 3 plots the demand curve of good i for different values of $P_D(i)/P_D$ and compares it to the CES demand curve (i.e., $\Psi = 0$). As shown there, because the elasticity increases as a firm raises its price, demand falls more for the VES demand curve than the CES demand curve. With a rising elasticity of demand, the upper right panel shows that a firm will reduce its desired markup in response to an idiosyncratic increase in its marginal cost that forces its price above those of its domestic competitors.

[19] For the CES demand curves, we exclude relative import prices from the instrument set, since the estimated system of equations no longer involves import prices.

The estimate of Ψ implies that demand for good i falls about 14 percent in response to a 2 percent increase in a firm's price above its steady-state value, and about 50 percent in response to a 5 percent increase. These estimates seem quite reasonable in contrast to the values discussed in V. V. Chari, Patrick J. Kehoe, and Ellen R. McGrattan (2000). They criticize the calibration of the demand curve in Kimball (1995), because 2 percent and 2.3 percent increases in a firm's price induce a 78 percent and 100 percent fall in demand.

Returning to the CES specification, the results in Table 1 suggest that there is upward bias in the degree of indexation for that model. In particular, the estimate of δ_D, the degree of indexation to lagged inflation, is large and statistically significant. In contrast, in the unrestricted VES specification, the coefficient on lagged inflation is smaller and not statistically significant. Intuitively, with the VES demand curves, inflation is inheriting persistence from movements in relative import prices, and as a result, one does not need the partial indexation scheme to compensate. Later, we report results from a Monte Carlo exercise that substantiate this interpretation.

Table 1 reports the Ljung-Box Q-statistic at lags 1 and 4. For the VES specification with indexation, we can reject the presence of serially correlated markup shocks. We also constructed a J test on the overidentifying restriction implied by the instrument set and failed to reject the model and the validity of the instruments.[20] For the CES specification, there is strong evidence that the markup shocks are serially correlated, suggesting that the model is misspecified.

To assess the fit of the VES model, Figure 4 plots predicted inflation, $\hat{\pi}_t^F$, defined as

$$\hat{\pi}_t^F = \delta_D \hat{\pi}_{t-1} + \kappa_D \left[\frac{1-\Psi}{1-\beta\rho_s}\, \hat{s}_t^F + \omega \frac{\epsilon_A}{\epsilon}\, \frac{\Psi(1+\beta\rho_{M2}L)}{1-\beta\rho_{M1}-\beta^2\rho_{M2}}\, \hat{p}_{Mt}^F \right], \tag{28}$$

using the estimates for δ_D, θ (which implies a value for κ_D), and Ψ, as well as the fitted values $\hat{s}_t^F$, and $\hat{p}_{Mt}^F$ from the auxiliary VAR equations. The dashed red line in the figure shows a four-quarter moving average of $\hat{\pi}_t^F$, while the solid black line shows a four-quarter moving average of observed inflation. Predicted inflation tracks the broad contours of observed inflation. In particular, the predicted series rises in the mid to late 1980s, trends downward with inflation in the 1990s, and rises and falls with observed inflation in the first half of this decade.

An important implication of our estimate of Ψ is that international competition plays an important role in influencing domestic inflation. To assess this role, the dashed blue line in Figure 4 plots predicted inflation for the CES specification in which $\Psi = 0$ and foreign prices do not influence the desired markups of domestic firms. As shown there, without this foreign competitiveness channel, the model fails to account for the increase in inflation in the late 1980s and its subsequent reversal in the early 1990s. Moreover, by neglecting the influence of foreign competition on desired markups, the CES specification overstates the level of inflation for the last seven years of our sample: the model predicts an average, annualized inflation rate of 0.3 percent from 2000 to 2006 compared to a slight deflation of 0.4 percent. In

[20] The J statistic is 0.2, well below its critical value of 3.84 for a test with a 95 percent significance level.

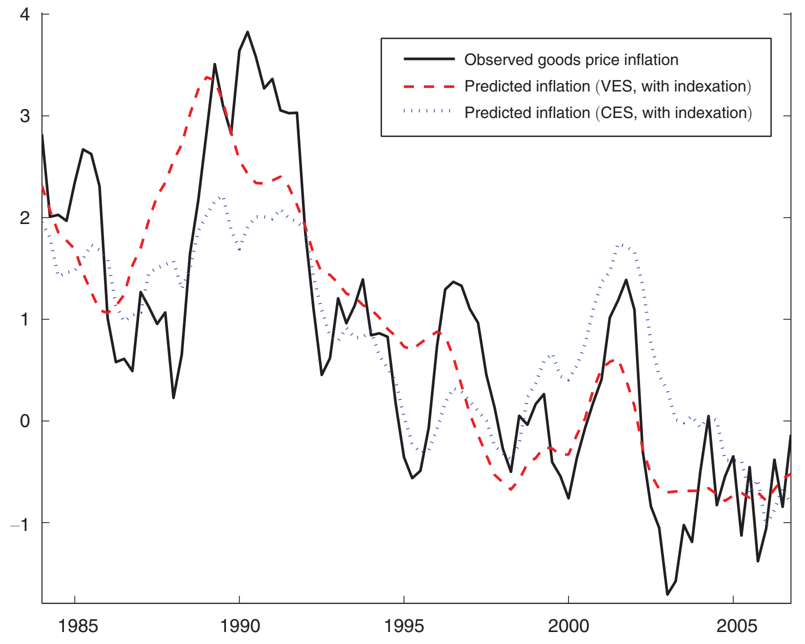

Figure 4. Actual and Predicted Inflation from Alternative Specifications (*Four-Quarter Moving Average*)

Notes: Predicted inflation is defined in equation (28) in the text. The estimated parameters used in constructing the predicted series for the VES specification are reported in the second column of Table 2, labeled "VES without indexation." The parameters used for the CES case appear in the fourth column of Table 2, labelled "CES without indexation."

contrast, the average value of predicted inflation for the VES specification is very close to the observed value over this period.

The VES model allows us to quantify how inflation responds to changes in foreign competition. In the 1990s, for instance, goods price inflation dropped about 4 percentage points on an annual basis. The estimates for the VES model attribute more than half of this decline to lower relative import prices.

We can also assess the role of foreign competition for inflation dynamics by computing its contribution to the volatility of the four-quarter change in domestic goods prices. For the VES specification, as shown in Table 1 in the row labelled "$\sigma_\pi F/\sigma_\pi$," predicted inflation accounts for nearly three-fourths of the volatility of observed inflation, with movements in relative import prices explaining about one-third of actual inflation volatility. In comparison, the CES specification that allows for lagged indexation only accounts for 37 percent of the volatility of inflation. Overall, our evidence implies that foreign competition has played an important role in explaining movements in domestic goods prices.

A. *Model Misspecification and Indexation*

The results shown in Table 1 suggested that the CES model, by excluding import prices, is misspecified. In particular, this specification appears to generate

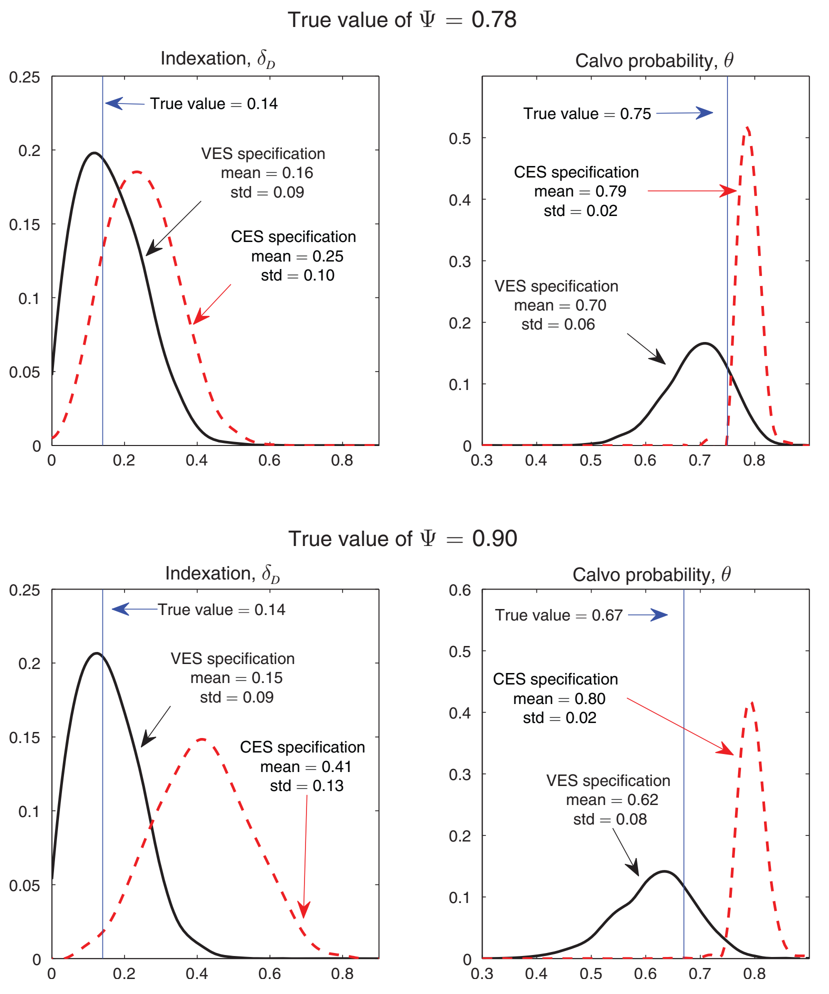

FIGURE 5. SAMPLING DISTRIBUTION OF ESTIMATES FROM ALTERNATIVE SPECIFICATIONS

Note: The VES specification described in equation (27) in the text is used as the data-generating process.

upwardbiased estimates of δ_D, the degree of indexation. We investigate this hypothesis by considering a Monte Carlo experiment in which we re-estimated the VES and CES specifications with indexation.[21] The top panels of Figure 5 plot the sampling distributions of our estimates for δ_D and θ, keeping the pseudo-true value of Ψ at 0.78. The estimate of δ_D from the VES specification appears to be unbiased with the mass of the distribution narrowly concentrated around its pseudo-true value, while the estimate of θ displays some small sample bias and a bit wider distribution than

[21] We use the VES specification with estimated pseudo-true values of $\Psi = 0.78$, $\delta_D = 0.14$, $\theta = 0.75$ to bootstrap 10,000 repetitions of artificial data, each with 96 observations (i.e., the length of 1983:Q1–2006:Q4 sample period).

implied by the asymptotic standard errors provided in Table 1. Still, these results suggest that our GMM estimator fares well in small samples.[22]

Figure 5 also shows that the misspecification bias of the CES formulation leads to estimates of δ_D and θ above their pseudo-true values. As shown in the bottom panels, the bias for δ_D and θ becomes more severe when we increase the pseudo-true value of Ψ from 0.78 to 0.9, and lower θ from 0.75 to 0.67.[23] In particular, the mean estimate of δ_D is 0.41 compared to its pseudo-true value of 0.14. This upward bias arises, because the misspecification associated with the omitted import price variable gives rise to serially correlated markup shocks. As a result, the estimate of δ_D rises above its pseudo-true value to help soak up this residual autocorrelation. Thus, an econometrician, who ignored the influence of foreign competition on inflation, may mistakenly conclude that lagged indexation plays an important role in explaining inflation.

B. *Comparison with the Literature*

As discussed earlier, Ψ can be used to gauge the degree of real rigidities associated with variations in desired markups arising from domestic competition. From equation (19), we can see that Ψ depends on both the steady-state demand elasticity or markup, and the elasticity of the demand elasticity with respect to a firm's price, $(\partial\epsilon(i)/\partial p_D(i))\ 1/\epsilon$. It is therefore a useful metric to compare our estimates with calibrated values of the Kimball (1995) preferences used in the literature.

Table 2 shows our estimated value for Ψ as well as the elasticity of the elasticity with respect to a firm's price. Although our estimates suggest that those discussed in Chari, Kehoe, and McGrattan (2000) are high, a number of researchers use calibrations that are validated by our results. In contrast, Dossche, Heylen, and den Poel (2006) use scanner data from a euro-area supermarket chain to argue that most calibrations of the Kimball (1995) aggregator impose too high a value of $(\partial\epsilon(i)/\partial p_D(i))\ 1/\epsilon$, as the median estimate for the goods they consider is only 0.8. However, given that they estimate a demand elasticity with a (net) markup of 250 percent, their implied estimate of Ψ is 0.67, close to our estimate. In our view, Ψ is the relevant metric for comparing results, since $(\partial\epsilon(i)/\partial p_D(i))\ 1/\epsilon$ is not a sufficient statistic for describing the demand curve or the degree of variation in desired markups.[24] Our estimate is also much lower than Bouakez (2005), who estimates $(\partial\epsilon(i)/\partial p_D(i))\ 1/\epsilon$ by calibrating the Calvo price setting parameter to be consistent with 4 quarter contracts.

Our results are also related to Nicoletta Batini, Brian Jackson, and Stephen Nickell (2005), who estimate an open economy NKPC for the United Kingdom in which foreign prices affect inflation due to both variations in desired markups and the presence of imported intermediate goods. In contrast to our results, they find that their measure of external competitiveness does not have a statistically significant

[22] See Jan M. Podivinsky (1999) for a review of the literature using Monte Carlo simulations to evaluate the small sample properties of GMM.

[23] This alternative parameterization holds fixed the value of $\kappa_D(1-\Psi)$, the reduced-form slope coefficient of real unit labor cost in equation (24).

[24] For example, for a very high markup, such as the one estimated by Dossche, Heylen, and den Poel (2006), the variation in the desired markup can be substantial without much variation in the demand elasticity.

Table 2—Comparison of Benchmark Estimates and Calibrated Demand Curves in the Literature

	ϵ	μ	$\frac{\partial \epsilon(i)}{\partial p_D(i)} \frac{1}{\epsilon}$	Ψ
Benchmark estimates	6	1.2	18.2	0.78
Chari, Kehoe, and McGrattan (2000)	10	1.11	300	0.97
Coenen, Levin, and Christoffel (2007)	5–20	1.05–1.25	10–33	0.47–0.89
Eichenbaum and Fisher (2007)	11	1.1	10–33	0.5–0.77
Dossche, Heylen, and den Poel (2006)[a]	1.4	3.5	0.8	0.67
Dotsey and King (2005)	10	1.11	60	0.87
Gust, Leduc, and Vigfusson (2006)	6	1.2	18.3	0.78
Bouakez (2005)	11	1.1	216	0.96

[a]Median estimated demand elasticity and curvature from their Table 5.

role in explaining the variation in inflation. However, there are a number of important differences in their paper. Most notably, they adopt an ad hoc specification for variations in desired markups.

In our purely forward-looking model, we estimate a value of θ, which implies an average contract duration of four quarters. This estimate is broadly consistent with the micro evidence of Nakamura and Steinsson (2008), who find a median duration of nonsale prices of 8 to 11 months using prices for both consumer's and producer's finished goods.[25] Our estimates are also broadly in line, though slightly higher, than those of Coenen, Levkin, and Christoffel (2007) and Eichenbaum and Fisher (2007), who incorporate both VES demand curves and firm-specific capital into NKPC.

Our estimate of an insignificant degree of indexation are in line with two recent papers by Ireland (2004) and Coenen, Levin, and Christoffel (2007). Ireland (2004) finds no role for indexation in a closed-economy model when he allows for serially autocorrelated markup shocks. In contrast, we use independently and identically distributed markup shocks to show that once we allow for endogenous variations in markups, lagged indexation is not significant. Coenen, Levin, and Christoffel (2007) estimate a closed-economy Phillips curve and argue that backward-looking price setting is not needed to explain aggregate inflation in the context of a stable monetary policy regime. Contrary to their analysis, our results do not hinge on the use of a dummy variable to account for a change in the US monetary policy regime occurring in 1991.[26]

C. *Alternative Calibrations*

Table 3 considers the sensitivity of our estimates to the calibrated values of ϵ_A and μ and also modifies our framework to allow for a time-varying import share. For

[25] The findings of Nakamura and Steinsson (2008) are also in line with earlier micro studies surveyed in John B. Taylor (1999). In contrast, Mark Bils and Klenow (2004) find a much higher frequency of price adjustment using micro data on consumer prices. The lower frequency of price changes in Nakamura and Steinsson (2008) largely reflects that they exclude temporary sales in measuring price changes, while Bils and Klenow (2004) include sales.

[26] If we included the 1991 dummy into our analysis, the estimates of θ and δ_D would fall, and the overall fit of the model would improve. However, we take a more conservative approach and exclude the dummy from our analysis.

Table 3—Estimates of VES Specification For Alternative Calibrations

	Benchmark[a]	$\epsilon_A = 0.5$	$\epsilon_A = 2$	$\mu = 1.1$	Variable import share[b]
θ	0.75	0.71	0.78	0.69	0.75
	(0.04)	(0.05)	(0.04)	(0.05)	(0.08)
Ψ	0.78	0.88	0.64	0.87	0.65
	(0.13)	(0.08)	(0.17)	(0.09)	(0.16)
δ_D	0.14	0.14	0.14	0.14	0.13
	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)

[a] The benchmark column refers to the model including firm-specific capital.
[b] Table 3 reports the estimated value of $\tilde{\Psi}$ of the variable import share model. See equation (31) in the text.

ease of comparison, Table 3 reports again the benchmark estimates from the VES specification with firm-specific capital and lagged indexation.

The second column of Table 3 shows the effect of lowering the import price elasticity, ϵ_A, from its benchmark value of 1.5 to 0.5, a value consistent with short-run estimates. In this case, the estimate of Ψ rises to 0.88, well within the 90 percent confidence interval of the benchmark model. Alternatively, an increase in ϵ_A to 2 lowers our estimate of Ψ to 0.64. This fall in Ψ, however, does not necessarily imply that foreign competition has a smaller effect on the desired markups of domestic firms. In particular, for a given value of Ψ, a higher import price elasticity raises the responsiveness of domestic firms' desired markups to foreign prices. Column 4 in Table 3 shows the estimation results using a markup of 10 percent, a value in line with the estimates of Basu and Fernald (1997). In this case, our benchmark estimate for Ψ rises to 0.87.

For the benchmark model, we assumed a constant steady-state import share, even though the observed share has gone up over the sample period. Although it is difficult to determine whether the import share will remain permanently higher, it is useful to examine the sensitivity of the results to this possibility. Accordingly, we derive a specification for the NKPC that assumes the economy is transitioning between two steady states, with the import share lower in the first than in the second.

One factor that may account for the rising trade share is the import of new goods.[27] The production of new goods would make the home bias parameter time-varying. We assume that

$$\omega_t = \omega_0 + \alpha_{\omega t,T} + u_{\omega t}, \tag{29}$$

where $u_{\omega t}$ is an *independently and identically distributed* process, $\alpha_{\omega t,T} = 0$ for $t < 1$, $\alpha_{\omega t,T} = (\omega_1 - \omega_0)\ t/T$ for $1 \geq t \geq T$, and $\alpha_{\omega t,T} = (\omega_1 - \omega_0)$ for $t > T$, where ω_0 and ω_1 denote the values of ω in the initial and final steady state, and $t = 1$ and $t = T$ denote the beginning and end of the sample period, respectively.

[27] For evidence on the importance of new goods in trade, see, for example, Timothy J. Kehoe and Kim J. Ruhl (2009). While the home bias parameter is exogenous in our framework, a number of papers have emphasized an extensive trade margin, where ω_t is endogenously determined. See, for example, Mark J. Melitz (2003), and Gust, Leduc, and Vigfusson (2006) for how to modify these preferences and how ω_t can be given the interpretation as an increase in the variety of imported goods.

A second factor that may account for the rising import share is a downward trend in relative import prices. Although it is difficult to determine whether relative import prices display such a trend using a small sample, we modify the benchmark process for this series to allow for this possibility:

$$\log p_{Mt} = \alpha_{Mt,T} + \tilde{p}_{Mt}, \tag{30}$$

where $\tilde{p}_{Mt}$ is a mean zero, AR(2) process. Also, $\alpha_{Mt,T} = 0$ for $t < 1$, $\alpha_{Mt,T} = \log(p_M)\, t/T$ for $1 \leq t \leq T$ and $\alpha_{Mt,T} = \log(p_M)$ for $t > T$, where p_M denotes the value of relative import prices in the second steady state.

As shown in the Appendix, under these assumptions, we can rewrite equation (25) as:

$$\hat{\pi}_t = a_s S_{\pi t} + \delta_D \hat{\pi}_{t-1} + \tilde{\kappa}_D \sum_{k=0}^{\infty} \beta^k E_t\Big[(1 - \tilde{\Psi})\hat{s}_{t+k} + \tilde{\Psi}\tilde{\omega}\frac{\epsilon_A}{\epsilon}\tilde{p}_{Mt+k} + a_\omega u_{\omega t+k}\Big], \tag{31}$$

where $S_{\pi t}$ is a deterministic, exogenous variable satisfying $S_{\pi t} = S_{\pi t+1} - \beta^t(T - t)/T$ with $S_{\pi t} = 0$ and $\tilde{\Psi} = \tilde{\nu}\mu/(1 + \tilde{\nu}\mu)$, and $\tilde{\nu} = \nu p_F^{\rho/(\gamma-\rho)}$. In equation (31), $\tilde{\Psi}$ has the same interpretation as Ψ, but now takes into account movements in relative prices associated with the transition to the steady state with the higher import share.[28] The parameters, $\tilde{\kappa}_D$ and $\tilde{\omega}$ are defined in the Appendix and are the counterparts to κ_D and ω in equation (25) that take into account the economy's transition to a higher import share.

Figure 2 shows that relative import prices have fallen about 2 percent from 1983 to 2006, which implies $p_M < 1$ given the normalization that the relative import price is 1 in the initial steady state. The fraction of imported goods to US goods production has risen from around 15 percent to about 38 percent over the same period. We choose $\omega_1 > \omega_0$ to match this rise in the import share. As shown in the Appendix, this calibration implies that $a_s < 0$, and as a result, inflation will inherit a downward trend, owing to both the increase in variety of imported goods and the small decline in relative import prices. The last column of Table 3 shows the estimates of θ, $\tilde{\Psi}$, and δ_D from equation (31). Allowing for the upward trend in the import share does not significantly affect the estimated degree of nominal and real rigidities.

D. *Alternative Data*

We chose the index for the benchmark import price series to encompass the broadest set of imported final goods, matching the basket of domestically produced final goods whose price inflation we investigate. However, this broad set includes the prices of some intermediate imported products. The second column of Table 4

[28] Notice that $\tilde{\Psi} = \Psi$ with $p_F = 1$, which is true when there are no transitional dynamics.

Table 4—Estimates of VES Specification Using Alternative Data

	Benchmark[a]	Alternative import prices	Oil and intermediate imported inputs	Longer sample
θ	0.75	0.73	0.82	0.79
	(0.04)	(0.04)	(0.04)	(0.05)
Ψ	0.78	0.76	0.74	0.75
	(0.13)	(0.16)	(0.18)	(0.17)
δ_D	0.14	0.18	0.17	0.32
	(0.09)	(0.09)	(0.08)	(0.10)

[a] The benchmark column refers to the model including firm-specific capital.

shows the estimates of equation (25) using an import prices series that excludes all intermediate goods, but at the cost of also excluding some final goods.[29] Though the point estimate of Ψ is lower in this case, the estimates are not significantly different from the benchmark.

Our model abstracts from the influence of oil and imported intermediate inputs in domestic production. To allow for this influence, we modify the production process of intermediate goods producers so that intermediate good i is produced according to a CES gross production function whose inputs are imported fuel and materials and the value-added from capital and labor. This production structure modifies a firm's marginal cost and inflation evolves according to

$$(32) \quad \hat{\pi}_t - \delta_D \hat{\pi}_{t-1} = \beta E_t[\hat{\pi}_{t+1} - \delta_D \hat{\pi}_t] + \kappa_D \Big\{ (1-\Psi)[(1-\omega_L)\hat{s}_t + \omega_L \hat{\tau}_t] + \Psi \omega \frac{\epsilon_A}{\epsilon} \hat{p}_{Mt} + \varphi \hat{\gamma}_t \Big\},$$

where τ_t denotes the price of imported fuel and materials, and ω_L is the share of these inputs in gross production.[30] The third column of Table 4 displays the estimates of θ, Ψ, and δ_D setting $\omega_L = 0.075$, based on the share of imported oil and materials in total production, and using the alternative import price series that includes only finished goods to measure p_{mt}. This modification results in a slightly lower value of Ψ and higher value of θ than in the benchmark case.

Finally, we used the 1983–2006 sample period to abstract from large changes in monetary policy that would cast doubt on the structural interpretation of the degree of indexation and the Calvo pricing parameter. The last column of Table 4 shows that the importance of foreign competition in influencing domestic inflation is robust to the use of the longer sample period (1975–2006).

[29] This series is constructed as the implicit deflator of the aggregate including imports of capital and consumer goods. See lines 31 and 36 in NIPA tables 4.2.5 and 4.2.3.

[30] This series is constructed as the implicit deflator of the aggregate including imports of industrial supplies and materials and petroleum products. See lines 27 and 30 in NIPA table 4.2.5 and 4.2.3.

Table 5—Estimates of VES Specification Under Alternative Assumptions[a,b]

	Benchmark VES[b]	VAR(2) forecasting model	Maximum likelihood
θ	0.75	0.67	0.77
	(0.04)	(0.06)	(0.05)
Ψ	0.78	0.75	0.74
	(0.13)	(0.18)	(0.17)
δ_D	0.14	0.12	0.14
	(0.09)	(0.09)	(0.08)

[a] Standard errors are reported in parentheses.
[b] The benchmark system includes an AR(1) process for real unit labor costs and an AR(2) for relative import prices. The VAR(2) model refers to replacing these parts of the benchmark system with an unrestricted VAR(2) model for real unit labor costs and relative import prices.

E. *Alternative Instruments and Estimation Procedures*

Table 5 compares the structural estimates for the VES model assuming firm-specific capital with two alternatives. In the benchmark specification for forecasting unit labor costs and import prices, we ignored any feedback between these variables by considering separate AR processes. In the third column, we consider an alternative forecasting process in which these variables are modeled as an unrestricted VAR(2).[31] Table 5 shows that the estimate of Ψ is somewhat larger in this case. However, overall, the restrictions we place on the forecasting model do not appreciably alter the estimates vis-à-vis the benchmark model.

The last column of Table 5 presents results from estimating our system of equations (i.e., the structural inflation equation and the two AR processes for unit labor costs and import prices) using maximum likelihood estimation (MLE). Despite this different estimation strategy, the results are similar to our GMM estimates.

We can also use the MLE estimates to test whether the restrictions implied by our structural model with VES demand are rejected by the data. To do this, we estimated an unrestricted VAR of order 2:

$$Z_t = B_1 Z_{t-1} + B_2 Z_{t-2} + v_t, \tag{33}$$

where Z_t includes goods inflation, real unit labor costs, and relative import prices. Our benchmark model involves estimating 6 parameters and, as discussed in Appendix II, places 11, zero restrictions on the coefficients in B_1 and B_2, plus one non-zero restriction. A likelihood ratio test fails to reject these restrictions.

Overall, we conclude that our results are robust to alternative calibrations, the forecasting process, the import price series, a trending import share, and the estimation method.

[31] For the estimates of the unrestricted forecasting model, see Guerrieri, Gust, and López-Salido (2008).

V. Conclusions

In this paper, we developed a structural model and showed that foreign competition has played an important role in accounting for the behavior of goods inflation through changes in desired markups of domestic firms. In particular, we found that foreign competition lowered domestic goods inflation by 2 percentage points in the 1990s. In addition, our results provided evidence in favor of demand curves which lead to endogenous variations in markups.

Although we view this as an important step in understanding how international factors influence domestic prices, goods production is about one-third of overall GDP. A rough estimate would suggest that foreign competition lowered overall GDP inflation about two-thirds of a percentage point in the 1990s. However, this estimate does not take into account any interaction between the traded and nontraded sectors, which may magnify these effects. We leave the exploration of this issue to future research.

Appendix

This Appendix is divided into two sections. In Appendix I, we derive the demand curves of the final goods producer as well as the log-linearized expression for inflation in the benchmark case and the case with a trending import share. In Appendix II, we discuss the relationship between the theoretical model and an unrestricted VAR.

I. Theoretical Derivations

A. *Deriving the Demand of a Domestically Produced Good*

To derive the demand curves for domestically produced goods, recall that the representative final goods producer maximizes equation (2) subject to the demand aggregator implied by equations (3)–(5). The first-order conditions associated with this problem are

$$\text{(A1)} \qquad P_{Dt}(i) = \frac{\Lambda_t}{A_t}\left[\frac{1-\nu}{1-\omega}\frac{A_{Dt}(i)}{A_t} + \nu\right]^{\gamma_t - 1} \times \left[V_{Dt}^{\frac{1}{\rho}} + V_{Mt}^{\frac{1}{\rho}}\right]^{\rho-1} V_{Dt}^{\frac{1}{\rho}-1}(1-\omega)^{\rho-1},$$

$$\text{(A2)} \qquad P_{Mt}(i) = \frac{\Lambda_t}{A_t}\left[\frac{1-\nu}{\omega}\frac{A_{Mt}(i)}{A_t} + \nu\right]^{\gamma_t - 1} \times \left[V_{Dt}^{\frac{1}{\rho}} + V_{Mt}^{\frac{1}{\rho}}\right]^{\rho-1} V_{Mt}^{\frac{1}{\rho}-1}\omega^{\rho-1},$$

where Λ_t is the Lagrange multiplier associated with equation (3). Before deriving the demand curves, we need to define $P_{Ft} = \Lambda_t / A_t$ and show that P_{Ft} satisfies equation (9).

To do so, rewrite equations (AI)–(A2) as:

$$\left[\frac{1-\nu}{\omega}\,\frac{A_{Dt}(i)}{A_t} + \nu\right] = \left(\frac{P_{Dt}(i)}{P_{Ft}}\right)^{\frac{1}{\gamma_t - 1}} \left[V_{Dt}^{\frac{1}{\rho}} + V_{Mt}^{\frac{1}{\rho}}\right]^{\frac{1-\rho}{\gamma_t - 1}} V_{Dt}^{\frac{\rho - 1}{\rho(\gamma_t - 1)}} (1-\omega)^{\frac{1-\rho}{\gamma_t - 1}},$$

$$\left[\frac{1-\nu}{\omega}\,\frac{A_{Mt}(i)}{A_t} + \nu\right] = \left(\frac{P_{Mt}(i)}{P_{Ft}}\right)^{\frac{1}{\gamma_t - 1}} \left[V_{Dt}^{\frac{1}{\rho}} + V_{Mt}^{\frac{1}{\rho}}\right]^{\frac{1-\rho}{\gamma_t - 1}} V_{Mt}^{\frac{\rho - 1}{\rho(\gamma_t - 1)}} \omega^{\frac{1-\rho}{\gamma_t - 1}}.$$

Substituting these expressions into equations (4)–(5), we can express V_{Dt} and V_{Mt} as

$$\text{(A3)}\quad V_{Dt} = \frac{1}{(1-\nu)\gamma_t}\left(\frac{P_{Dt}}{P_{Ft}}\right)^{\frac{\gamma_t}{\gamma_t - 1}} \left[V_{Dt}^{\frac{1}{\rho}} + V_{Mt}^{\frac{1}{\rho}}\right]^{\frac{\gamma_t(1-\rho)}{\gamma_t - 1}} V_{Dt}^{\frac{\gamma_t(\rho-1)}{(\gamma_t - 1)\rho}} (1-\omega)^{\frac{\gamma_t - \rho}{\gamma_t - 1}}$$

$$\text{(A4)}\quad V_{Mt} = \frac{1}{(1-\nu)\gamma_t}\left(\frac{P_{Mt}}{P_{Ft}}\right)^{\frac{\gamma_i}{\gamma_i - 1}} \left[V_{Dt}^{\frac{1}{\rho}} + V_{Mt}^{\frac{1}{\rho}}\right]^{\frac{\gamma_i(1-\rho)}{\gamma_i - 1}} V_{Mt}^{\frac{\gamma_i(\rho-1)}{(\gamma_i - 1)\rho}} \omega^{\frac{\gamma_i - \rho}{\gamma_i - 1}},$$

where the price indices, P_{Dt} and P_{Mt}, are defined in equation (8). Using equations (A3) and (A4), the ratio of V_{Dt} to V_{Mt} is given by

$$\text{(A5)}\qquad \left(\frac{V_{Dt}}{V_{Mt}}\right)^{\frac{1}{\rho}} = \left(\frac{P_{Dt}}{P_{Mt}}\right)^{\frac{\gamma_t}{\gamma_t - \rho}} \frac{(1-\omega)}{\omega}.$$

Since optimal behavior by a final goods producer implies that equation (3) holds with equality, we can rewrite it as

$$\text{(A6)}\qquad \left[\left(\frac{V_{Dt}}{V_{Mt}}\right)^{\frac{1}{\rho}} + 1\right]^{\rho} V_{Mt} = \frac{1}{(1-\nu)\gamma_t}.$$

It is useful to express equation (A4) as

$$V_{Mt} = \frac{1}{(1-\nu)\gamma_t}\left(\frac{P_{Mt}}{P_{Ft}}\right)^{\frac{\gamma_t}{\gamma_t - 1}} \left[\left(\frac{V_{Dt}}{V_{Mt}}\right)^{\frac{1}{\rho}} + 1\right]^{\frac{\gamma_t(1-\rho)}{\gamma_t - 1}} \omega^{\frac{\gamma_t - \rho}{\gamma_t - 1}}.$$

Substituting this expression and equation (A5) into equation (A6), we have,

$$\left[\left(\frac{PDt}{PMt}\right)^{\frac{\gamma_t}{\gamma_t-\rho}} \frac{(1-\omega)}{\omega} + 1\right]^{\frac{\gamma_t-\rho}{\gamma_t-1}} \omega^{\frac{\gamma_t-\rho}{\gamma_t-1}} P_{Mt}^{\frac{\gamma_t}{\gamma_t-1}} = P_{Ft}^{\frac{\gamma_t}{\gamma_t-1}}.$$

This expression, with some manipulation, can be written as

$$PFt = \left[(1-\omega)P_{Dt}^{\frac{\gamma_t}{\gamma_t-\rho}} + \omega P_{Mt}^{\frac{\gamma_t}{\gamma_t-\rho}}\right]^{\frac{\gamma_t-\rho}{\gamma_t}},$$

which is equation (9).

With P_{Ft} defined in this way, we can now turn to deriving the demand curve for a domestically-produced good, i.e., equation (7). We begin by re-expressing equation (A1) as

$$\text{(A7)} \quad \left[\frac{1-\nu}{1-\omega}\frac{A_{Dt}(i)}{A_t} + \nu\right]$$

$$= \left(\frac{P_{Dt}(i)}{P_{Ft}}\right)^{\frac{1}{\gamma_t-1}} \left[1 + \left(\frac{V_{Mt}}{V_{Dt}}\right)^{\frac{1}{\rho}}\right]^{\frac{1-\rho}{\gamma_t-1}} (1-\omega)^{\frac{1-\rho}{\gamma_t-1}}.$$

Note that equation (A5) implies

$$1 + \left(\frac{VMt}{VDt}\right)^{\frac{1}{\rho}} = \frac{P_{Dt}^{\frac{\gamma_t}{\rho-\gamma_t}}}{1-\omega}\left[(1-\omega)P_{Dt}^{\frac{\gamma_t}{\gamma_t-\rho}} + \omega P_{Mt}^{\frac{\gamma_t}{\gamma_t-\rho}}\right],$$

or

$$\text{(A8)} \quad 1 + \left(\frac{V_{Mt}}{V_{Dt}}\right)^{\frac{1}{\rho}} = \frac{1}{1-\omega}\left(\frac{P_{Ft}}{P_{Dt}}\right)^{\frac{\gamma_t}{\gamma_t-\rho}}.$$

Substituting equation (A8) into equation (A7) yields

$$\left[\frac{1-\nu}{1-\omega}\frac{A_{Dt}(i)}{A_t} + \nu\right] = \left(\frac{P_{Dt}(i)}{P_{Ft}}\right)^{\frac{1}{\gamma_t-1}} \left(\frac{P_{Dt}}{P_{Ft}}\right)^{\frac{\gamma_t}{\gamma_t-\rho}\frac{1-\rho}{\gamma_t-1}}.$$

Rearranging this expression, we get equation (7):

$$A_{Dt}(i) = (1-\omega)\left[\frac{1}{1-\nu}\left(\frac{P_{Dt}(i)}{P_{Dt}}\right)^{\frac{1}{\gamma_t-1}}\left(\frac{P_{Dt}}{P_{Ft}}\right)^{\frac{\rho}{\gamma_t-\rho}} - \frac{\nu}{1-\nu}\right]A_t.$$

B. *Deriving the Log-Linearized Pricing Equation*

To derive equation (20), we begin by defining the contract price, $P^c_{Dt}(i) = P_{Dt}(i)/P_{Dt}$, for a firm that optimally chooses its price at date t. Using this definition in equation (11) and log-linearizing, we get:

$$\text{(B1)}\quad \hat{P}^c_{Dt}(i) = \sum_{j=1}^{\infty}(\beta\theta)^j(\hat{\pi}_{Dt+j} - \delta_D\hat{\pi}_{Dt+j-1}) + (1-\beta\theta)\sum_{j=0}^{\infty}(\beta\theta)^j\left[\hat{s}_{t+j} - \frac{1}{\epsilon - 1}\,\hat{\epsilon}_{t+j}(i)\right].$$

In the above equation, $\hat{\epsilon}_t(i)$ is the log-linearized version of the elasticity of demand for good i given by

$$\text{(B2)}\quad \hat{\epsilon}_{t+j}(i) = \nu\epsilon\left(\hat{P}^c_{Dt}(i) - \sum_{k=1}^{j}(\hat{\pi}_{Dt+k} - \delta_D\hat{\pi}_{Dt+k-1}\right) - \nu\epsilon_A\hat{p}_{Ft+j} + \frac{\gamma}{1-\gamma}\,\hat{\gamma}_{t+j},$$

where $\hat{p}_{Ft}$ is the log-linearized price index consisting of all of the prices of a firm's competitors relative to the domestic price index, (i.e., $p_{Ft} = P_{Ft}/P_{Dt}$). Substituting this expression for the elasticity of demand into equation (B1), we have:

$$\text{(B3)}\quad \hat{P}^c_{Dt}(i) = \sum_{j=1}^{\infty}(\beta\theta)^j\left(\hat{\pi}_{Dt+j} - \delta_D\hat{\pi}_{Dt+j-1}\right) + \frac{1-\beta\theta}{1+\frac{\nu\epsilon}{\epsilon-1}}\sum_{j=0}^{\infty}(\beta\theta)^j\left[\hat{s}_{t+j} + \frac{\nu\epsilon_A}{\epsilon-1}\,\hat{p}_{Ft+j} - \frac{\gamma(\epsilon-1)^{-1}}{1-\gamma}\,\hat{\gamma}_{t+j}\right].$$

Using the definition of the steady-state markup $\big($i.e., $\mu = \epsilon/(\epsilon - 1)\big)$ and the definition of Ψ $\big($i.e., $\Psi = \nu\mu/(1+\nu\mu)\big)$, this expression, after quasi-differencing, can be rewritten as

$$\text{(B4)}\quad \hat{P}^c_{Dt}(i) - \beta\theta\hat{P}^c_{Dt+1}(i) = \beta\theta(\hat{\pi}_{Dt+1} - \delta_D\hat{\pi}_{Dt}) + (1-\beta\theta)\left[(1-\Psi)\hat{s}_t + \Psi\frac{\epsilon_A}{\epsilon}\hat{p}_{Ft} + (2\Psi - 1)\hat{\gamma}_t\right].$$

From the log-linearized version of the first expression in equation (8), the contract price at date t can be related to traded goods inflation via

$$\text{(B5)}\quad \hat{P}^c_{Dt}(i) = \frac{\theta}{1-\theta}(\hat{\pi}_{Dt} - \delta_D\hat{\pi}_{Dt-1}).$$

Substituting this expression into equation (B4), we get an expression relating domestic price inflation to real marginal cost and p_{Ft}:

$$\text{(B6)} \qquad \hat{\pi}_{Dt} - \delta_D \hat{\pi}_{Dt-1} = \beta(\hat{\pi}_{Dt+1} - \delta_D \hat{\pi}_{Dt}) + \kappa\Big[(1 - \Psi)\hat{s}_t + \Psi \frac{\epsilon_A}{\epsilon} \hat{p}_{Ft} + (2\Psi - 1)\hat{\gamma}_t\Big].$$

The log-linearized version of equation (9) implies that

$$\hat{p}_{Ft} = \omega \hat{p}_{Mt}.$$

Using this expression in equation (B7) yields equation (2).

C. *Deriving the Log-Linearized Pricing Equation in the Variable Import Share Model*

To derive equation (31), the log-linearized pricing equation with transition dynamics, we need to take into account that the relative import price (p_M) and the index of competitors' prices relative to domestic prices (p_F) may differ from one in the non-stochastic steady state. In this case, the log-linearized first order condition for price setting becomes:

$$\text{(C1)} \qquad \hat{P}^c_{Dt}(i) = \sum_{j=1}^{\infty} (\beta\theta)^j (\hat{\pi}_{Dt+j} - \delta_D \hat{\pi}_{Dt+j-1}) + (1 - \beta\theta) \sum_{j=0}^{\infty} (\beta\theta)^j \Big[\hat{s}_{t+j}(i) - \frac{1}{\tilde{\epsilon} - 1} \hat{\epsilon}_{t+j}(i)\Big],$$

where $\tilde{\epsilon} = 1/(1 - \gamma)(1 - \tilde{\nu})$, $\tilde{\nu} = \nu p_F^{\rho/(\gamma - \rho)}$, and $\hat{s}_t(i)$ refers to firm-specific marginal cost as we have assumed that capital is immobile across firms. Also, the log-linearized elasticity of demand for good i, in this case, is given by

$$\text{(C2)} \qquad \hat{\epsilon}_{t+j}(i) = \tilde{\nu}\, \tilde{\epsilon} \left(\hat{P}^c_{Dt}(i) - \sum_{k=1}^{j} (\hat{\pi}_{Dt+k} - \delta_D \hat{\pi}_{Dt+k-1})\right) - \tilde{\nu}\, \tilde{\epsilon}_A \hat{p}_{Ft+j},$$

where $\tilde{\epsilon}_A = \rho/(\rho - \gamma)(1 - \tilde{\nu})$. Without loss of generality, we have abstracted from the shock to γ_t.

Given the assumption that a domestic firm only sells its good in the domestic market (i.e., $Y_t(i) = A_{Dt}(i)\ \forall i$), firm specific marginal cost can be written as

$$\text{(C3)} \qquad \hat{s}_t(i) - \hat{s}_t = -\tilde{\epsilon} \frac{1 - \alpha}{\alpha} \hat{P}^c_{Dt}(i).$$

Substituting this expression and equation (C2) into equation (C1) yields

$$\text{(C4)}\quad \hat{P}^{c}_{Dt}(i) = \sum_{j=1}^{\infty} (\beta\theta)^{j} \left(\hat{\pi}_{Dt+j} - \delta_D \hat{\pi}_{Dt+j-1}\right) + \frac{1 - \beta\theta}{1 + \frac{1-\alpha}{\alpha}\tilde{\epsilon} + \frac{\tilde{\nu}\,\tilde{\epsilon}}{\tilde{\epsilon} - 1}} \sum_{j=0}^{\infty} (\beta\theta)^{j} \left\{\hat{s}_{t+j} + \frac{\tilde{\nu}\,\tilde{\epsilon}}{\tilde{\epsilon} - 1}\,\frac{\tilde{\epsilon}_A}{\tilde{\epsilon}}\,\tilde{p}_{Ft+j}\right\}.$$

Using equation (B5), we can rewrite this as

$$\text{(C5)}\quad \hat{\pi}_{Dt} - \delta_D \hat{\pi}_{Dt-1} = \beta(\hat{\pi}_{Dt+1} - \delta_D \hat{\pi}_{Dt}) + \frac{\kappa}{1 + \frac{1-\alpha}{\alpha}\tilde{\epsilon}\,(1 - \tilde{\Psi})}\left[(1 - \tilde{\Psi})\hat{s}_t + \tilde{\Psi}\,\frac{\tilde{\epsilon}_A}{\tilde{\epsilon}}\,\tilde{p}_{Ft}\right],$$

where $\tilde{\Psi} = \tilde{\nu}\mu/(1 + \tilde{\nu}\mu)$, and $\tilde{\nu} = \nu p_F^{\rho/(\gamma - \rho)}$. Log-linearizing equation (9) around the second steady state and taking into account that ω_t is now time-varying yields

$$\text{(C6)}\qquad \hat{p}_{Ft} = \tilde{\omega}\hat{p}_{Mt} + a_{\omega}\,(\omega_t - \omega_1),$$

where $\tilde{\omega} = \omega_1(p_M/p_F)^{(\gamma - \rho)/\gamma}$ and $a_{\omega} = -(1/\tilde{\omega})(\gamma/(\gamma - \rho))p_F^{(\rho - \gamma)/\gamma}(1 - p_M^{\gamma/(\gamma - \rho)}) < 0$. Combining equations (29) and (30) into equation (A20) and substituting into equation (A19) leads to

$$\text{(C7)}\quad \hat{\pi}_{Dt} - \delta_D \hat{\pi}_{Dt-1} = \beta(\hat{\pi}_{Dt+1} - \delta_D \hat{\pi}_{Dt}) + \frac{\kappa}{1 + \frac{1-\alpha}{\alpha}\tilde{\epsilon}(1 - \tilde{\Psi})}\left[(1 - \tilde{\Psi})\hat{s}_t + \tilde{\Psi}\,\frac{\tilde{\epsilon}_A}{\tilde{\epsilon}}\,\hat{p}_{Ft}\right].$$

Noting that $\tilde{\epsilon}_A/\tilde{\epsilon} = \epsilon_A/\epsilon = \big((1 - \gamma)\rho/(\rho - \gamma)\big) > 0$ and solving this expression forward yields equation (31), where

$$\tilde{\kappa}_D = \frac{\kappa}{\left[1 + \frac{1-\alpha}{\alpha}\,\frac{(1 - 2\tilde{\Psi})(1 - \tilde{\Psi})}{(1 - \gamma)(1 - \tilde{\Psi}(2 - \gamma))}\right]},$$

and $a_s = (\tilde{\kappa}_D \tilde{\Psi}\tilde{\omega}\,\epsilon_A/\epsilon)a_{\pi}$ with $a_{\pi} = \log(p_M) + a_{\omega}(\omega_1 - \omega_0) < 0$. In estimating equation (31), we set $\omega_0 = 0.15$, $\omega_1 = 0.34$, $\rho = 0.54$ and $\gamma = 1.2$ and choose p_F to satisfy:

$$p_F = \left[(1 - \omega_1) + \omega_1 p_M^{\frac{\gamma}{\gamma - \rho}}\right]^{\frac{\gamma - \rho}{\gamma}}.$$

II. The Restricted VAR

Equation (33) can be used to express the benchmark theoretical model as a VAR(2) with coefficient matrices:

$$B_1 = \begin{pmatrix} \delta_D & \frac{\kappa_D(1 - \Psi)\rho_s}{1 - \beta\rho_s} & \frac{\kappa_D \omega^{\frac{\epsilon_A}{\epsilon}} \Psi(\rho_1 + \beta\rho_2)}{1 - \beta\rho_1 - \beta^2 \rho_2} \\ 0 & \rho_s & 0 \\ 0 & 0 & \rho_1 \end{pmatrix} B_2 = \begin{pmatrix} 0 & 0 & \frac{\kappa_D \omega^{\frac{\epsilon_A}{\epsilon}} \Psi\rho_2}{1 - \beta\rho_1 - \beta^2\rho_2} \\ 0 & 0 & 0 \\ 0 & 0 & \rho_2 \end{pmatrix}.$$

Our procedure involves calibrating β, α, ϵ, ϵ_A, and ω and estimating six parameters: δ_D, Ψ, θ, ρ_s, ρ_1, ρ_2 in addition to the constants (which we suppress for convenience) and the variance-covariance matrix. Relative to the unconstrained estimation of equation (33), our theoretical model places no restrictions on the variance-covariance matrix but involves 11 zero restrictions on B_1 and B_2 plus one non-zero restriction of the form: $B_2(3, 3)\ B_1(1, 3) = (B_1(3, 3) + \beta B_2(3, 3))B_2(1, 3)$.

Imposing these restrictions and taking the calibrated parameters as given, there is a one-to-one mapping between the reduced-form VAR coefficients and the structural parameters. To see this mapping, note that $\delta_D = B_1(1, 1)$, $\rho_s = B_1(2, 2)$, $\rho_1 = B_1(3, 3)$ and $\rho_2 = B_2(3, 3)$. The parameter Ψ can be determined from the reduced-form coefficients using

$$\Psi = \left[1 + \frac{\omega^{\frac{\epsilon_A}{\epsilon}} (1 - \beta\rho_s)(\rho_1 + \beta\rho_2) B_1(1, 2)}{(1 - \beta\rho_1 - \beta^2 \rho_2)\rho_s B_1(1, 3)}\right]^{-1},$$

while κ_D is pinned down by

$$\kappa_D = \rho_s \left[B_1(1, 2) + \frac{1 - \beta\rho_1 - \beta^2\rho_2}{(1 - \beta\rho_s)(\rho_1 + \beta\rho_2)\omega^{\frac{\epsilon_A}{\epsilon}}} B_1(1, 3)\right].$$

The structural parameter θ can then be determined from the relationship

$$\kappa_D = \frac{(1 - \beta\theta)(1 - \theta)}{(1 - \theta)\left(1 + \epsilon \frac{\alpha}{1 - \alpha}(1 - \Psi)\right)}.$$

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