IMF Working Papers 15/33

On the First-Round Effects of International Food Price Shocks: the Role of the Asset Market Structure

INTERNATIONAL MONETARY FUND

WP/15/33

IMF Working Paper

On the First-Round Effects of International Food Price Shocks: the Role of the Asset Market Structure

Rafael Portillo and Luis-Felipe Zanna

INTERNATIONAL MONETARY FUND

 WP/15/33

IMF Working Paper

Research Department

On the First-Round Effects of International Food Price Shocks: the Role of the Asset Market Structure

Prepared by Rafael Portillo and Luis-Felipe Zanna*

Authorized for distribution by Andrew Berg

February 2015

Abstract

We develop a tractable small open-economy model to study the first-round effects of international food price shocks in developing countries. We define first-round effects as changes in headline inflation that, holding core inflation constant, help implement relative price adjustments. The model features three goods (food, a generic traded good and a non-traded good), varying degrees of tradability of the food basket, and alternative international asset market structures (complete and incomplete markets, and financial autarky). First-round effects depend crucially on the asset market structure and the different transmission mechanisms they trigger. Under complete markets, inter-temporal substitution prevails, making the inflationary impact of international food prices proportional to the food share in consumption, which in developing economies is typically large. Under financial autarky, the income channel is dominant, and first-round effects are instead proportional to the country's food balance—the difference between the country's food endowment and its consumption—which in developing countries is typically small. The latter result holds regardless of the degree of food tradability. Incomplete markets yield a combination of the two extremes. Our results cast some doubt on the view that international food price shocks are inherently inflationary in developing countries.

JEL Classification Numbers: E3; F41; O11.

Keywords: Food Price Shocks; First-Round Effects; Developing Countries; New-Keynesian Models; Asset Market Structure.

Author's E-Mail Addresses: rportillo@imf.org; fzanna@imf.org.

* We have benefited from comments and conversations with Andy Berg, Ed Buffie, Doug Gollin, Peter Montiel, and Steve O'Connell and participants of the 2014 CSAE conference at Oxford University. All errors remain ours. This paper is part of a research project on macroeconomic policy in low-income countries supported by U.K.'s Department for International Development (DFID), and it should not be reported as representing the views of the International Monetary Fund or of DFID.

Table of Contents

Page

I. Introduction ... 3

II. The Model ... 6
A. The Representative Consumer ... 6
B. The Consumption Basket and Prices ... 8
C. The Non-Traded Sector ... 9
D. Monetary Policy: Identifying First-Round Effects ... 9
E. Market Clearing Conditions and Model Closure ... 11
F. Definition of the First-Round Effects Equilibrium and the Steady State ... 11

III. Analytical Solution ... 12
A. The Log-linear Version of the Model ... 12
A.1. The Link between Inflation, Relative Prices and First-Round Effects ... 14
B. Solving for the First-Round Effects ... 14
C. Remarks ... 17

IV. Calibration and a Graphic Representation ... 19
A. Calibration ... 19
B. Graphic Representation ... 20
C. Sensitivity Analysis ... 22

V. Extension: Incomplete Tradability of the Food Basket ... 25
A. Analytical Solution Under Incomplete Food Tradability ... 26

VI. Conclusions ... 29

Tables
Table 1. Benchmark Calibration ... 19

Figures
Figure 1. First-Round Effects: Financial Autarky, Complete and Incomplete Markets ... 21
Figure 2. First-Round Effects: Varying the Intra-temporal Elasticity of Substitution. ... 23
Figure 3. First-Round Effects: Varying the Portfolio Adjustment Costs Parameter and the Persistence of International Food Prices ... 24
Figure 4. First-Round Effects: Varying the Tradable Food Share ... 28

Appendix
A. Proofs of Propositions and Corollaries ... 30
A.1. Proof of Proposition 1 ... 30
A.2. Proof of Proposition 2 ... 30
A.3. Proof of Proposition 3 ... 30
A.4. Proof of Corollary 1 ... 32

References ... 33

I. Introduction

Developing economies have faced large swings in international food prices in recent years. A common policy adage on the response to these shocks—and commodity prices in general—is that the central bank should accommodate "first-round" effects but respond to "second-round" effects.[1] What is meant by first-round effects is not always explicit, but they are usually assumed to capture the direct impact of food price shocks on the consumer price index (CPI) and, therefore, to depend on the weight of food in this index. These direct effects are usually contrasted with second-round effects, which involve spillovers from food prices to wage and core inflation. Implicit in the policy advice is the notion that an increase in commodity prices requires an adjustment in relative prices and macroeconomic aggregates. Since an increase in headline (CPI) inflation, as a result of food price shocks, can help implement these necessary adjustments, the first part of the adage is implemented in practice by excluding temporary food price movements from core inflation and using this inflation as the nominal anchor of monetary policy. Moreover, as theory suggests, the choice of this anchor is not innocuous.[2] Core inflation embodies the distortions resulting from nominal price rigidities. Therefore, stabilizing core—rather than headline inflation—is desirable from a welfare perspective and justifies the second part of the adage.[3]

Most of the academic literature on responding to first- and\or second-round effects, or equivalently on stabilizing headline versus core inflation, has focused on whether the objective of core inflation stabilization is robust to various assumptions about the structure of the economy. Not surprisingly, various caveats have emerged. For instance, some increase in core inflation (second-round effects) may be desirable in the presence of nominal wage stickiness to help implement the necessary decrease in real wages, as discussed by Bodenstein et al. (2008). Moreover, with real wage rigidities, stabilizing core inflation may be too costly in terms of output stabilization, as argued by Blanchard and Galí (2007). Furthermore, when a country has some market power over its exports, a terms-of-trade externality arises, calling for greater exchange rate stability at the expense of stabilizing core inflation, as discussed by De Paoli (2009a). Present this export market power as well as perfect risk sharing in international markets, Catao and Chang (2010) show that targeting the CPI inflation welfare-dominates targeting core inflation; a result that may also hold under limited asset participation, as pointed out by Anand and Prasad (2010).

Nonetheless there has been little work in understanding first-round effects per se and how they depend on the structure of the economy. This is at odds with typical concerns of policy makers during food price shocks. Since food makes up a large share of consumption expenditure in developing economies, policy makers worry that the inflationary effects of food price shocks could be large as

[1] To our knowledge, this advice has its origins in policy decisions taken by the Bundesbank in the 1970s, which in the face of shocks to the international price of oil raised its one-year-ahead inflation objective to accommodate the inflation caused by the shock (see Bernanke et al., 1999). The standard advice likely became more clearly articulated with the adoption of inflation targeting regimes, as these helped focus the policy discussion on better understanding the sources of inflation and tailoring the policy response accordingly. From an academic perspective, although not explicitly stated, the advice can be traced back to the seminal work of Robert Gordon (1975).

[2] See Woodford (2003), among others.

[3] See Aoki (2001).

captured by the following quote: *"These movements in world commodity [food and oil] prices play a major role in driving headline inflation [...]. This is especially the case in emerging and developing economies where commodities are a sizable share of consumer price baskets."*[4] But is it always the case that first-round effects depend positively on the share of food in consumption, so that countries with higher food shares should experience larger increases in inflation? Or are there other, possibly mitigating, factors? More generally, what determines the size of these first-round effects?

In this paper, we study the determinants of first-round effects in a tractable small open-economy model. The model has three goods: a sticky-price non-traded good, a flexible-price food, and a flexible-price generic traded good. It also features a domestic endowment of food, varying degrees of tradability of the food basket, and various specifications of the country's access to international financial markets—complete markets, financial autarky and incomplete markets.[5] The tractability of our model allows us to provide analytical solutions of various equilibria that represent the real adjustment to temporary shocks to international food prices. Key in our analysis is the assumption that the central bank has the technology to perfectly stabilize core (sticky-price non-traded goods) inflation. As such, we can abstract from nominal price rigidities and provide a clear definition of first-round effects.

We provide a model-based definition of first-round effects: increases in headline inflation that, holding core inflation perfectly stabilized, help implement the required relative-price and macroeconomic adjustment. In this case, inflation is simply given by (minus) changes in the relative price of non-traded goods. The larger the decline in the relative price of non-traded goods, the larger the first-round effects of food price shocks. Our model-based definition of first-round effects captures, even before spill-overs to core inflation are considered, the inherent inflationary pressures associated with commodity price shocks. In addition, it provides a consistent definition in the context of a new-Keynesian framework, which is the workhorse model for modern monetary policy analysis.

With the help of the model, we obtain the following results. First, except for very specific parametrizations of the model, we find that first-round effects rarely correspond to the *direct* effects of food price shocks on headline inflation, whose size coincides exactly with the weight of (traded) food in the CPI. Policy makers usually (mis)interpreted these direct effects as first-round effects. Holding the share of food in the CPI constant, the range of first-round effects of an international price shock is in principle large, depending on the share of non-traded goods, the elasticity of substitution between goods, the inter-temporal elasticity of substitution, and the labor supply elasticity.

Second, and more importantly, we show that first-round effects crucially depend on the international asset market structure and are not necessarily proportional to the food share in the CPI:

- Under complete markets—the preferred specification in open-economy new-Keynesian models

[4] "Managing Inflation in an Era of Commodity Price Volatility." Opening Remarks by the Deputy Managing Director, Mr Naoyuki Shinohara, at a Joint ADB-IMF-Reserve Bank of India Seminar, New Delhi, India May 3, 2013. Available at: https://www.imf.org/external/np/speeches/2013/050313.htm

[5] Our focus on asset markets is inspired by De Paoli (2009b), who shows the key role that the latter plays for the design of monetary policy in small open economy models. We make the related point that the asset structure also matters for first-round effects.

but the one that is least likely to capture the state of affairs in developing economies—the inflationary impact of international food price shocks *is* proportional to the food share in the CPI.[6] In this case, the real effects of international food shocks depend solely on the *inter-temporal substitution* effects they trigger, which themselves depend on the share of food in the CPI. The larger the food share, the larger the increase in the relative price of the domestic consumption basket, and the larger the incentive to temporarily reduce aggregate consumption. This larger decline in consumption is then associated with a larger decrease in the relative price of non-traded goods and therefore with larger first-round effects.[7] The overall effect also depends on the degree of tradability of the food basket: the lower the share of food that is traded, the smaller the inflationary effects. In addition, the domestic endowment of food does not play a role in the adjustment, and only serves to pin down the trade surplus/deficit that would follow the increase in international food prices. As developing countries have large food shares, complete markets then predict large first-round effects.

- Under financial autarky, the inflationary impact is instead proportional to the country's net food balance (the difference between the country's food endowment and its food consumption) rather than the food share in the CPI. The key mechanism stems from the impact of the shock on the country's external income (*income* effects). If the country is self-sufficient in food, there are no balance-of-payment pressures from increases in international food prices, no pressures for the relative price of non-traded goods to change, and hence no inflationary pressures. If the relative price of non-traded goods were to fall, the country would demand less traded goods overall and an incipient current account surplus would arise. This incipient surplus would appreciate the nominal exchange rate—and reduce the relative price of non-traded goods—up to the point where the balance of payment clears again. This striking result stems from the inability to run a current account surplus (or deficit) in response to the shock. In addition, for a given food balance, the degree of tradability of the food basket is *irrelevant* for the inflationary impact of the shock, since the food balance itself is all that matters for the effect of the shock on the balance of payments and, therefore, on inflation. As food balances in developing countries are, on average, small—about one or two percentage points of GDP—financial autarky then predicts tiny increases in inflation (or even deflation if the country is a net food exporter).

- Under incomplete markets, domestic agents can accumulate non-contingent bonds subject to portfolio adjustment costs and can, in principle, run current account surpluses or deficits in response to the shock. In this case, the first-round effects depend on both the share of food in consumption and on the country's overall food balance, and the solution is a weighted combination of the previously discussed two asset market specifications. While the weight of food in the CPI still captures the *substitution* effects associated with the shock, the food balance now captures its *wealth* effects; the more persistent the shock is, the larger the wealth effects and the more important the country's food balance becomes in conditioning the inflationary response. Larger portfolio adjustment costs push the equilibrium toward the financial autarky case.

[6] Most New–Keynesian small open economy models follow the seminal work by Gali and Monacelli (2005), which assumes complete markets.

[7] Note that the presence of food in the basket drives a wedge between the real exchange rate and the inverse of the relative price of non-traded goods: the former can appreciate even though the relative price of non-traded goods decreases. This point has been emphasized by Catao and Chang (2010).

Third, a calibration exercise suggests that it is far from obvious that first-round effects should be large in countries with relatively high food shares in consumption. In particular, we calibrate the model to a generic/median sub-Saharan African country, and alternative specifications yield very different inflationary pressures. Under complete markets a 1 percent increase in international food prices can result in an increase in first-round inflation of as much as 0.27 percent, if food is fully traded. This is large but considerably smaller than the direct effect of 0.5 percent, which corresponds to the median food share times the shock. Under financial autarky, the median increase in inflation is close to 0.01 percent, which is tiny. Under incomplete markets, the median increase in inflation falls somewhere in-between (0.09 percent if food is fully traded). In addition, while the inflationary effect varies, in all cases a nominal appreciation offsets either a large part or most of the direct effect of the shock. The wide range of estimates, both across asset market specifications and relative to the food share, underscores the challenges of quantifying first-round effects, including for policy purposes.

The remainder of this paper is organized as follows. Section II presents the model. Section III provides an analytical solution, while section IV discusses the model's calibration and provides a graphic representation of the solution and a sensitivity analysis. Section V extends the model to analyze the case of incomplete tradability of the food basket. Finally, section VI concludes.

II. The model

A. The Representative Consumer

The representative consumer chooses a stream of consumption baskets c_t, labor efforts n_t and holdings of nominal assets to maximize lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \iota \frac{n_t^{1+\psi}}{1+\psi} \right),$$

where $\beta \in (0,1)$ is the subjective discount factor, $\sigma > 0$ is the inverse of the intertemporal elasticity of substitution, and $\psi > 0$ is the inverse of the Frisch elasticity of labor supply. E_0 denotes the expectations operator. Expectations are rational.

The representative consumer is also subject to the budget constraint:

$$P_t c_t + B_t + \phi_1 E_t\{Q_{t+1} D_{t+1}\} + \phi_2 S_t \left[B_t^* + \mathcal{H}(B_t^*)\right] =$$

$$W_t n_t + \Omega_{N,t} + P_{F,t} y_F + P_{T,t} y_T - T_t + R_{t-1} B_{t-1} + \phi_1 D_t + \phi_2 S_t R^* B_{t-1}^*. \quad (1)$$

P_t is the consumer price index (CPI), W_t is the nominal wage and $\Omega_{N,t}$ are profits from the non-traded sector. We assume the agent is endowed with two types of traded goods: food y_F and a generic traded-good y_T, valued at prices $P_{F,t}$ and $P_{T,t}$, respectively. T_t are government taxes and B_t denotes holdings of a non-contingent nominal domestic bond that pays gross interest R_t at time $t+1$. The bond is not traded internationally.

We consider several international asset market structures: complete and incomplete markets, and financial autarky. The combination of the parameters ϕ_1 and ϕ_2, in equation (1), captures these various options: the pair $\{\phi_1 = 0,\ \phi_2 = 0\}$ implies financial autarky; $\{\phi_1 = 1,\ \phi_2 = 0\}$ captures complete (contingent) markets; and $\{\phi_1 = 0,\ \phi_2 = 1\}$ reflects incomplete markets.[8]

Under complete markets, $D_{t,t+1}$ denotes time-t holdings of contingent claims, which pay one unit of currency if a specific state of nature is realized (in period $t+1$) and nothing otherwise, and $Q_{t,t+1}$ is the one-period stochastic discount factor for that state of nature. With incomplete markets, B_t^* refers to a non-contingent bond, denominated in foreign currency (S_t is the nominal exchange rate), which pays a free-risk gross interest R^* and is subject to portfolio adjustment costs $\mathcal{H}(B_t^*)$, as in Schmitt-Grohé and Uribe (2003):

$$\mathcal{H}(B_t^*) = \frac{v}{2}(B_t^*)^2.$$

These costs ensure the stationarity of the country's net foreign asset position (B_t^*) and allow us to model various degrees of international capital mobility depending on the value of v.

Intertemporal utility maximization leads to the following first-order conditions:

$$c_t{}^{-\sigma} = \beta E_t \left\{ \frac{R_t}{\pi_{t+1}} c_{t+1}{}^{-\sigma} \right\}, \tag{2}$$

and

$$\iota \frac{n_t^{\psi}}{c_t^{-\sigma}} = w_t, \tag{3}$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation rate and $w_t \equiv \frac{W_t}{P_t}$ is the real wage. These conditions—representing, respectively, the Euler equation related to domestic bonds B_t and the equation that equalizes the marginal rate of substitution between labor and consumption to the real wage—hold regardless of the international asset market structure. When ($\phi_1 = 1$), the maximization problem results in a state-specific Euler equation related to the state-contingent bonds $D_{t,t+1}$:

$$c_t{}^{-\sigma} = \frac{\beta}{Q_{t+1}\pi_{t+1}} c_{t+1}{}^{-\sigma}, \tag{4}$$

which holds across all states of nature; while for incomplete markets ($\phi_1 = 0$ and $\phi_2 = 1$) the maximization problem yields a different Euler equation related to the non-contingent bond B_t^*:

$$c_t{}^{-\sigma} = \beta R^* E_t \left\{ \left(\frac{s_{t+1}}{s_t} \right) \left(\frac{1}{1 + v b_t^*} \right) c_{t+1}{}^{-\sigma} \right\}, \tag{5}$$

where $s_t \equiv \frac{S_t P^*}{P_t}$ is the CPI-based real exchange rate and $b_t^* \equiv \frac{B_t^*}{P^*}$ with P^* denoting the foreign CPI which, for simplicity, is assumed to be constant and equal to one. Depending on the international market structure, corresponding transversality conditions hold.

[8]Once $\phi_1 = 1$, the value of ϕ_2 does not matter: access to a complete set of contingent assets makes incomplete (non–contingent) assets redundant.

B. The Consumption Basket and Prices

The consumption basket is the following:

$$c_t = \left[\alpha_N^{\frac{1}{\eta}} c_{N,t}^{\frac{\eta-1}{\eta}} + \alpha_F^{\frac{1}{\eta}} c_{F,t}^{\frac{\eta-1}{\eta}} + (1-\alpha_N-\alpha_F)^{\frac{1}{\eta}} c_{T,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}.$$

The triplet $(c_{N,t}, c_{F,t}, c_{T,t})$ denotes consumption of non-traded goods, food and the generic traded good, respectively; α_N (α_F) is the share of non-traded goods (food) in consumption; and η is the elasticity of substitution. Cost minimization leads to the following demand functions:

$$c_{N,t} = \alpha_N \left(\frac{P_{N,t}}{P_t} \right)^{-\eta} c_t = \alpha_N p_{N,t}^{-\eta} c_t, \tag{6}$$

$$c_{F,t} = \alpha_F \left(\frac{P_{F,t}}{P_t} \right)^{-\eta} c_t = \alpha_F p_{F,t}^{-\eta} c_t, \tag{7}$$

and

$$c_{T,t} = (1-\alpha_N-\alpha_F) \left(\frac{P_{T,t}}{P_t} \right)^{-\eta} c_t = (1-\alpha_N-\alpha_F) p_{T,t}^{-\eta} c_t. \tag{8}$$

$P_{i,t}$ is the price of good i with $i = N, F, T$. The triplet $(p_{N,t}, p_{F,t}, p_{T,t})$ denotes the price of each good relative to the CPI, which is given by:

$$P_t = \left[\alpha_N P_{N,t}^{1-\eta} + \alpha_F P_{F,t}^{1-\eta} + (1-\alpha_N-\alpha_F) P_{T,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}. \tag{9}$$

In our baseline specification, we assume the domestic prices of food and the generic traded good are given by the law of one price:

$$P_{F,t} = S_t P_{F,t}^* \quad \text{and} \quad P_{T,t} = S_t P^*, \tag{10}$$

where $P_{F,t}^*$ is the international nominal price of food. This assumption implies the following domestic relative prices:

$$p_{F,t} = s_t p_{F,t}^*, \quad \text{and} \quad p_{T,t} = s_t. \tag{11}$$

Lower case $p_{F,t}^* \equiv \frac{P_{F,t}^*}{P^*}$ is the international relative price of food, which we assume is exogenous and time-varying.

Using equations (9)-(11), it is possible to write CPI (gross) inflation as:

$$\pi_t = \left[\alpha_N \left(p_{N,t-1} \pi_{N,t} \right)^{1-\eta} + \alpha_F \left(s_{t-1} p_{F,t-1}^* \pi_{F,t} \right)^{1-\eta} + (1-\alpha_N-\alpha_F) \left(s_{t-1} \pi_{T,t} \right)^{1-\eta} \right]^{\frac{1}{1-\eta}}, \tag{12}$$

where $\pi_{i,t}$ denotes (gross) inflation of good i with $i = N, F, T$, satisfying the following:

$$\pi_{N,t} = \left(\frac{p_{N,t}}{p_{N,t-1}} \right) \pi_t, \quad \pi_{F,t} = \left(\frac{s_t}{s_{t-1}} \right) \left(\frac{p_{F,t}^*}{p_{F,t-1}^*} \right) \pi_t, \quad \text{and} \quad \pi_{T,t} = \left(\frac{s_t}{s_{t-1}} \right) \pi_t. \tag{13}$$

C. The Non-Traded Sector

The non-traded sector is composed of a continuum of monopolistic competitors, each providing a variety $y_{N,t}(i)$, with $i \in [0,1]$, and facing the following Dixit-Stiglitz aggregate demand for variety i:

$$y_{N,t}(i) = \left(\frac{P_{N,t}(i)}{P_{N,t}}\right)^{-\epsilon} y_{N,t},$$

where ϵ is elasticity of substitution between varieties, $P_{N,t}(i)$ is the price charged by firm i and $P_{N,t}$ is the price index for the entire sector: $P_{N,t} = \left[\int P_{N,t}(i)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$. Production of non-traded varieties is given by $y_{N,t}(i) = n_t(i)$.

Firms set prices for their varieties to maximize their profits. As in Calvo (1983), firms are not allowed to change their prices unless they receive a random signal. The probability that a given price can be re-optimized in any particular period is constant and equal to $(1-\theta)$. If firm i gets the random signal at time t, it chooses a reset price $\overline{P}_{N,t}(i)$ to maximize its discounted stream of expected profits:

$$Max\ E_t \sum_{j=0}^{\infty} (\beta\theta)^j \lambda_{t+j} \left[\left(\frac{\overline{P}_{N,t}(i)}{P_{N,t+j}}\right)^{-\epsilon} y_{N,t+j}\left(\overline{P}_{N,t}(i) - W_{t+j}(1-\delta)\right)\right],$$

where λ_{t+j} is the stochastic discount factor, and δ is an employment subsidy.

Profit maximization results in the following reset price:

$$\overline{P}_{N,t} = \frac{\epsilon}{\epsilon-1}(1-\delta)\frac{E_t \sum_{j=0}^{\infty}(\beta\theta)^j \lambda_{t+j}\left[\left(\frac{1}{P_{N,t+j}}\right)^{-\epsilon} y_{N,t+j} W_{t+j}\right]}{E_t \sum_{j=0}^{\infty}(\beta\theta)^j \lambda_{t+j}\left[\left(\frac{1}{P_{N,t+j}}\right)^{-\epsilon} y_{N,t+j}\right]}. \tag{14}$$

The aggregate price index in the non-traded sector $P_{N,t}$ is the weighted sum of those prices $\overline{P}_{N,t}$ that were reset (with mass $1-\theta$) and those prices that were not reset that can be approximated by yesterday's price index $P_{N,t-1}$ (with mass θ):

$$P_{N,t} = \left[(1-\theta)\overline{P}_{N,t}{}^{1-\epsilon} + \theta P_{N,t-1}{}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}.$$

D. Monetary Policy: Identifying First-Round Effects

There is an interesting parallel between the standard monetary policy advice in response to food and energy prices shocks and the results of the new-Keynesian literature on the inflation measure that central banks should target. The standard policy advice is to allow for the direct first-round effects on headline inflation, but not for the second-round effects that may be present in the response of wages and in turn core prices.[9] A related monetary policy issue, especially for inflation targeters, is to determine

[9] See International Monetary Fund (2011), among others. The policy objective in this case is to avoid persistent effects on inflation. The first-round or direct effects—which also include the effects associated with the use of oil as an

the most appropriate inflation measure that should serve as the target that guides policy decisions by central banks. In general, the new-Keynesian literature advocates for targeting core inflation and not headline inflation.[10] But by targeting a core inflation measure—excluding flexible and volatile prices, such as those associated with food and energy—the monetary authority ends implementing, to a great extent, the standard advice of allowing for first-round effects while reacting to second-round effects.

We invoke this parallel to identify the first-round effects in our new-Keynesian model. Our approach consists in focusing on the flexible-price equilibrium that arises in a new-Keynesian model where the central bank has the monetary policy technology to perfectly stabilize core inflation—i.e., sticky-price non-traded goods inflation.[11] By doing this, we abstract in our model from nominal price-rigidity issues and, therefore, from second-round effects. As we will elaborate below, this means that the inflation dynamics will be determined by the (negative) changes in the relative price of non-traded goods, which are supposed to be non-persistent and associated with the first-round effects. This approach to isolate the first-round effects is not uncommon in the new-Keynesian literature. Woodford (2011), for instance, proposes to identify the size of the government expenditure multiplier "when monetary policy is unchanged," by assuming that the monetary authority is endowed with a technology that keeps the *real* interest rate constant.

Given our identification strategy, we can further simplify the equilibrium conditions that drive the dynamics of the economy. We focus then on a symmetric equilibrium where $P_{N,t-1}(i) = P_{N,t-1} = P_{N,0}$ for all $i \in [0,1]$ and

$$y_{N,t} = n_t. \tag{15}$$

We assume that, using its perfectly-stabilizing-inflation technology, the central bank sets core inflation equal to one—i.e., $\pi_{N,t} = 1$, for $t = 1, 2, ..., \infty$. This implies that $P_{N,t} = P_{N,t+1} = ... = P_{N,0}$ and that the reset price $\overline{P}_{N,t}$ must also equal $P_{N,0}$ in equation (14). For simplicity, but without loss of generality, we assume the employment subsidy corrects the monopolistic distortion—i.e., $\delta = 1/\epsilon$. Then the Calvo pricing equation (14) holds if:[12]

$$p_{N,t} = w_t, \tag{16}$$

which reflects labor demand decisions and implies zero profits ($\Omega_{N,t} = 0$).

To complete the specification of policies in this model, we assume the government follows a passive fiscal policy by setting taxes (T_t) to satisfy its budget constraint at all times ($B_t = R_{t-1}B_{t-1} + \delta w_t n_t -$

intermediate production input—capture changes in relative prices in the economy and therefore their impact on headline inflation should be short-lived. In contrast, the second-round effects involve increases in prices that are more persistent, including those that result from pressures to preserve real wage levels.

[10] See for instance Aoki (2001), among others, in the context of the New Keynesian literature.

[11] The exchange rate is assumed to be flexible.

[12] To see this, use $\overline{P}_{N,t} = P_{N,0}$ and set $\delta = 1/\epsilon$ in equation (14) and divide both sides of this equation by $P_{N,0}$ to obtain

$$1 = \frac{E_t \sum_{j=0}^{\infty} (\beta\theta)^j \lambda_{t+j} \left[y_{N,t+j} \frac{W_{t+j}}{P_{N,t+j}} \right]}{E_t \sum_{j=0}^{\infty} (\beta\theta)^j \lambda_{t+j} \left[y_{N,t+j} \right]},$$

which holds if:

$$\frac{W_{t+j}}{P_{N,t+j}} = 1 \quad \text{for} \quad j = 0, 1, ...$$

T_t). For simplicity we assume it does not have access to foreign bonds/claims.

E. Market Clearing Conditions and Model Closure

The market clearing condition in the non-traded sector can be expressed as

$$c_{N,t} = y_{N,t} = n_t. \tag{17}$$

While combining the labor supply equation (3) with the labor demand equation (16) yields the market clearing condition of the labor market

$$\iota \frac{n_t^{\psi}}{c_t^{-\sigma}} = w_t = p_{N,t}. \tag{18}$$

We close the model using the various asset structures described earlier.

Under financial autarky ($\phi_1 = 0$ and $\phi_2 = 0$), the representative agent cannot buy or sell financial assets to foreigners. Total demand for traded goods must therefore equal the value of domestic endowments:

$$s_t p_{F,t}^* c_{F,t} + s_t c_{T,t} = s_t p_{F,t}^* y_F + s_t y_T. \tag{19}$$

Under complete markets ($\phi_1 = 1$ and $\phi_2 = 0$), we can combine equation (4) with a similar condition for foreign consumers and derive the following equilibrium condition:[13]

$$c_t = \varphi s_t^{\frac{1}{\sigma}} c^*, \tag{20}$$

where c^* is foreign consumption, which is assumed to be constant, and φ denotes initial conditions. Under complete markets, c_t will deviate from φc_t^* only if the domestic basket becomes more or less expensive than the foreign one, i.e., only if the real exchange rate appreciates or depreciates.

Under incomplete markets ($\phi_1 = 0$ and $\phi_2 = 1$), the country's balance of payment now includes the accumulation of foreign assets, interest income from abroad and portfolio adjustment costs:

$$s_t p_{F,t}^* c_{F,t} + s_t c_{T,t} + s_t \left[b_t^* + \mathcal{H}(b_t^*) \right] = s_t p_{F,t}^* y_F + s_t y_T + s_t R^* b_{t-1}^*. \tag{21}$$

For simplicity, we set $P^* = 1$, which implies $\mathcal{H}(B_t^*) = \mathcal{H}(b_t^*)$.

F. Definition of the First-Round Effects Equilibrium and the Steady State

We now provide a definition of the first-round effects equilibrium for the case of autarky.

[13] See Backus and Smith (1992).

Definition 1 *Given $\{y_T, y_F\}$ and the stochastic process $\{p^*_{F,t}\}_{t=0}^{\infty}$, a first-round effects equilibrium under autarky is a set of stochastic processes $\{c_t,\ c_{N,t},\ c_{F,t},\ c_{T,t},\ n_t,\ y_{N,t},\ R_t,\ p_{N,t},\ p_{T,t},\ p_{F,t},\ w_t,\ s_t,\ \pi_t,\ \pi_{N,t},\ \pi_{F,t},\ \pi_{T,t}\}_{t=0}^{\infty}$ satisfying (i) the optimal conditions (2) and (6)-(8); (ii) the definitions (11)-(13); (iii) the central bank's policy that perfectly stabilizes core inflation as $\pi_{N,t} = 1$; (iv) the market clearing conditions (17) and (18); and (v) the closing condition (19).*

Similar definitions could be provided for complete markets or incomplete markets. For the case of complete markets, the equilibrium definition would also consider the stochastic process $\{Q_{t+1}\}_{t=0}^{\infty}$ and the Euler equation (4), while it would replace the closing condition (19) by (20). On the other hand, the equilibrium definition under incomplete markets would include the stochastic process $\{b^*_t\}_{t=0}^{\infty}$ and the Euler equation (5), and it would replace the closing condition (19) by (21).

The steady state is the same across all international asset structure specifications. We impose the condition $\beta R^* = 1$, which in the case of incomplete market imposes $b^* = 0$. More generally, we set aggregate consumption, relative prices, and gross inflation to 1:

$$c = s = p_N = p^*_F = w = \pi = 1.$$

Steady-state values of (c_N, c_F, c_T) are given by $(\alpha_N, \alpha_F, 1 - \alpha_N - \alpha_F)$, respectively. Variables y_N and n also equal α_N, which requires $\iota = \alpha_N^{-\psi}$. Finally, we set $y_F = \kappa_F$, which imposes $y_T = 1 - \alpha_N - \kappa_F$.

III. Analytical Solution

A. The Log-linear Version of the Model

We log-linearize the equations of the model around the non-stochastic steady state and present the equations that describe the dynamics of the economy, depending on the international asset market structure.

Financial Autarky (FA)

Under FA, the equations of the first-round effects equilibrium in Definition 1 can be reduced, after some algebra, to a system of two equations:

$$\hat{c}_t = \frac{1 + \eta\psi}{\psi + \sigma} \hat{p}_{N,t}, \tag{22}$$

and

$$\hat{c}_t = -\frac{\alpha_N \eta}{1 - \alpha_N} \hat{p}_{N,t} - \frac{\alpha_F - \kappa_F}{1 - \alpha_N} \hat{p}^*_{F,t}, \tag{23}$$

where a hat ˆ indicates percent deviations from steady state. Equation (22) describes internal balance: the relation between aggregate consumption ($\hat{c}_t$) and the relative price of non-traded goods ($\hat{p}_{N,t}$) that ensures equilibrium in the non-traded goods sector and the labor market. The relation is straightforward: an increase in $\hat{p}_{N,t}$ results in a decrease in the demand for non-traded goods and an increase in the supply of labor; an increase in overall consumption is therefore required to increase non-traded demand and reduce labor supply, through the Frisch labor supply curve (3). Equation (23) describes external balance—the clearing of the balance of payments (bop). In this case, an increase in $\hat{p}_{N,t}$ results in an increase in traded goods demand; a decrease in $\hat{c}_t$ is then required to clear the bop. $\hat{p}^*_{F,t}$ operates as an exogenous shifter of the external balance curve.

Complete Markets (CM)

Under CM, internal balance remains the same as in (22). We derive an alternative external balance condition, by combining the log-linear versions of equations (9) and (20):

$$\hat{c}_t = -\frac{\alpha_N}{(1-\alpha_N)\,\sigma}\hat{p}_{N,t} - \frac{\alpha_F}{(1-\alpha_N)\,\sigma}\hat{p}^*_{F,t}. \tag{24}$$

Note that, unlike equation (23), this alternative condition does not reflect the need to clear the balance of payments. Instead, it describes how changes in relative prices affect the representative agent's demand for current consumption, through their effect on the risk sharing condition (20). Because of this, external balance under complete markets does not depend on the economy's endowment of food. This will have important consequences for the inflationary effect of food shocks.

Incomplete Markets (IM)

Finally, under IM, the solution of the model can be reduced to a system of three equations. First, the internal balance equation, which is the same as (22). The second equation—which is derived from combining equations (7),(8),(9), (11), and (21)—is the relation between $\hat{p}_{N,t}$, $\hat{c}_t$ and $\hat{b}^*_t$ that clears the balance of payments:[14]

$$\hat{c}_t = -\frac{\alpha_N \eta}{1-\alpha_N}\hat{p}_{N,t} - \frac{\alpha_F - \kappa_F}{1-\alpha_N}\hat{p}^*_{F,t} - \frac{1}{1-\alpha_N}\hat{b}^*_t + \frac{R^*}{1-\alpha_N}\hat{b}^*_{t-1}. \tag{25}$$

Unlike financial autarky, accumulation or decumulation of foreign assets now allow the representative agent to consume more or less traded goods than the value of his endowment.

The third equation is the relation between present and future values of $(\hat{c}_t, \hat{p}_{N,t}, \hat{p}^*_F)$ and $\hat{b}^*_t$ implied by combining the Euler equation (5) with equation (9):

$$\hat{c}_t = E_t\hat{c}_{t+1} - \frac{\alpha_N}{(1-\alpha_N)\,\sigma}\left(\hat{p}_{N,t} - E_t\hat{p}_{N,t+1}\right) - \frac{\alpha_F}{(1-\alpha_N)\,\sigma}\left(\hat{p}^*_{F,t} - E_t\hat{p}^*_{F,t+1}\right) + \frac{v}{\sigma}\hat{b}^*_t. \tag{26}$$

Consumption now depends on future values of domestic and foreign relative prices, while the portfolio adjustment cost encourages agents to increase consumption when they accumulate net foreign assets (as these lower their net return).

Because of the forward looking nature of the Euler equation, the solution of the model is no longer static. To characterize expectations of future variables, we need to specify stochastic processes for international relative prices:

$$\hat{p}^*_{F,t} = \rho_{p^*_F}\hat{p}^*_{F,t-1} + \epsilon_{p^*_F,t}, \tag{27}$$

where $\rho_{p^*_F} \in (0,1)$ captures the persistence of the process and $\epsilon_{p^*_F,t}$ is an *iid* shock.

[14] Here $\hat{b}^*_t$ indicates deviations of b^*_t from its steady-state value (0) in percent of steady state consumption.

A.1. The Link between Inflation, Relative Prices and First-Round Effects

Under the assumption that the monetary authority always stabilizes core inflation—i.e., $\hat{\pi}_{N,t} = 0$—equation (13) implies that headline inflation is given by (minus) changes in the relative price of non-traded goods:

$$\Delta \hat{p}_{N,t} = \hat{p}_{N,t} - \hat{p}_{N,t-1} = \hat{\pi}_{N,t} - \hat{\pi}_t \;\leftrightarrow\; \hat{\pi}_t = -\Delta \hat{p}_{N,t}. \tag{28}$$

As a result, first-round effects from international food price shocks will be determined by the impact of these shocks on the relative price of non-traded goods. To motivate and provide some preliminary insights of our analysis, it is helpful to use this expression and the *direct* effect of the commodity price shock on inflation—the effect $\alpha_F \Delta \hat{p}^*_{F,t}$ holding all domestic nominal prices constant, except the nominal price of food, which in policy circles is often (mis)interpreted as the first-round effect—to obtain:

$$\hat{\pi}_t - \alpha_F \Delta \hat{p}^*_{F,t} = -\left(\Delta \hat{p}_{N,t} + \alpha_F \Delta \hat{p}^*_{F,t}\right).$$

From this, it is clear that unless the change in the relative price of non-traded goods $\Delta \hat{p}_{N,t}$ fully offsets the direct effect $\alpha_F \Delta \hat{p}^*_{F,t}$, the first-round effect may not necessarily coincide with this direct effect, in which the share of food on the CPI α_F plays such a crucial role. For instance, if the relative price of non-traded goods falls by less than the direct effect of the shock ($\Delta \hat{p}_{N,t} > -\alpha_F \Delta \hat{p}^*_{F,t}$) then inflation also increases by less than the direct effect.

Of further interest is that, given the assumption of full tradability of the food basket and the choice of the nominal anchor, differences between actual inflation and the direct effect must come from changes in the nominal exchange rate $\Delta \hat{S}_t$. To see this, use equations (9), (10) and $\pi_{N,t} = 1$ to derive

$$\hat{\pi}_t = (1-\alpha_N)\Delta \hat{S}_t + \alpha_F \Delta \hat{p}^*_{F,t} \;\leftrightarrow\; \Delta \hat{S}_t = \frac{1}{1-\alpha_N}\left(\hat{\pi}_t - \alpha_F \Delta \hat{p}^*_{F,t}\right) = -\frac{1}{1-\alpha_N}\left(\Delta \hat{p}_{N,t} + \alpha_F \Delta \hat{p}^*_{F,t}\right).$$

In the case of $\Delta \hat{p}^*_{F,t} = 0$, any resulting increase in inflation would come from a nominal depreciation.

What determines $\Delta \hat{p}_{N,t}$, and therefore the first-round effects, in our model? The answer depends on the international asset market structure. We proceed to demonstrate this point formally.

B. Solving for the First-round Effects

We now provide analytical solutions for the impact of food shocks on inflation, under financial autarky, complete markets, and incomplete markets. In the first two cases, the solution is straightforward since the models are static. In the third case, we rely on the method of undetermined coefficients to find the policy rules that ensure non-explosive dynamics.

Proposition 1 *Under **financial autarky (FA)**, there exists a unique rational expectations equilibrium for inflation, which is given by:*

$$\hat{\pi}^{FA}_t = \Phi^{FA}_{p^*_F} \Delta \hat{p}^*_{F,t}, \tag{29}$$

with

$$\Phi^{FA}_{p^*_F} = \left[\frac{(\psi+\sigma)}{(1+\eta\psi)(1-\alpha_N)+\eta(\psi+\sigma)\alpha_N}\right](\alpha_F-\kappa_F),$$

and where the first-round effects, due to changes in international food prices, depend on $\Phi^{FA}_{p^*_F}$.

Proof. *See the Appendix A.* ■

Proposition 1 reveals that, under FA, the impact of international food prices on inflation is proportional to the net food balance, since $\Phi^{FA}_{p^*_F}$ depends directly on $\alpha_F - \kappa_F$. This result derives from the role of the balance of payment (bop) in the adjustment process. To see why, we begin by assuming that the increase in international food prices initially results in a decline of the relative price of non-traded goods (i.e., initially $\Delta\hat{p}_{N,t} = -\alpha_F\Delta\hat{p}^*_{F,t}$), and consider three cases: zero initial food balance ($\alpha_F = \kappa_F$), food deficit ($\alpha_F > \kappa_F$), and food surplus ($\alpha_F < \kappa_F$). If the country has a zero initial food balance, the higher food bill is exactly offset by the higher value of the food endowment. In this case, the initial drop in $\hat{p}_{N,t}$ would result in an incipient trade surplus, as consumers would switch away from traded goods (in general) and toward non-traded goods. The excess net supply of traded goods would then require a nominal appreciation, undoing the original decrease in $\Delta\hat{p}_{N,t}$ and helping rebalance trade. The bop would clear only when the nominal appreciation has completely offset the direct effect of the food price increase: $\Delta\hat{S}_t = -\frac{\alpha_F}{(1-\alpha_N)}\Delta\hat{p}^*_{F,t}$, which implies inflation would not change ($\hat{\pi}^{FA}_t = \Delta\hat{p}_{N,t} = 0$).[15] If the country is a net food importer, then $\hat{p}_{N,t}$ must decline—and inflation increase—to help reestablish external balance. However, the required adjustment depends on the initial bop pressure—again, holding expenditure on traded goods constant at first—which itself depends on the starting net food balance. If the country is a net food exporter, then $\hat{p}_{N,t}$ must increase and inflation must decrease!

Proposition 2 *Under* ***complete markets (CM)****, there exists a unique rational expectations equilibrium for inflation, which is given by:*

$$\hat{\pi}^{CM}_t = \Phi^{CM}_{p^*_F}\Delta\hat{p}^*_{F,t}, \tag{30}$$

with

$$\Phi^{CM}_{p^*_F} = \left[\frac{(\psi+\sigma)}{(1+\eta\psi)\sigma(1-\alpha_N)+(\psi+\sigma)\alpha_N}\right]\alpha_F,$$

and where the first-round effects, due to changes in international food prices, depend on $\Phi^{CM}_{p^*_F}$.

Proof. *See the Appendix A.* ■

The results of Proposition 2 for CM contrast sharply with those from Proposition 1 for FA. In particular note that under CM the food endowment κ_F has no impact on the coefficient $\Phi^{CM}_{p^*_F}$, which

[15] In this case, the CPI-based real exchange rate appreciates by the same magnitude as the nominal exchange rate: $\Delta\hat{s}_t = \Delta\hat{S}_t$. Note that while inflation does not change, the increase in international food prices has real effects, namely on the composition of trade. The real appreciation increases consumption of the generic traded good and a "generic" trade deficit opens up, and the opposite occurs for food. Overall trade remains balanced, however.

determines the first-round impact of international food prices on inflation. In this case, changes in these prices have an effect on inflation only to the extent they affect the relative price of the domestic basket, and the representative consumer's demand for current consumption. This channel is proportional to the share of food on the consumption basket α_F, and in this sense it may capture the policy concerns about inflationary pressures in developing economies that typically feature high shares of food.

Since FA and CM can be probably seen as two extreme market structures, we consider next the case of incomplete markets.

Proposition 3 *Under* ***incomplete markets (IM)****, there exists a unique rational expectations equilibrium for inflation, which is given by:*

$$\hat{\pi}_t^{IM} = \Phi_{p_F^*}^{IM} \Delta \hat{p}_{F,t}^* - \Phi_{b^*}^{IM} \Delta \hat{b}_t^*, \tag{31}$$

with

$$\Phi_{p_F^*}^{IM} = \omega_{p_F^*} \Phi_{p_F^*}^{CM} + (1 - \omega_{p_F^*}) \Phi_{p_F^*}^{FA},$$

and

$$\Phi_{b^*}^{IM} = \frac{(\psi + \sigma)}{(1 + \eta\psi)(1 - \alpha_N) + (\psi + \sigma)\alpha_N \eta} (\mathfrak{a} - R^*),$$

where

$$\mathfrak{a} = \frac{1}{2} \left\{ 1 + R^* + \gamma v (1 - \alpha_N) - \sqrt{[1 + R^* + \gamma v (1 - \alpha_N)]^2 - 4R^*} \right\} \in (-1, 1)$$

and

$$\gamma = \frac{(1 + \eta\psi)(1 - \alpha_N) + (\psi + \sigma)\alpha_N \eta}{(1 + \eta\psi)(1 - \alpha_N)\sigma + (\psi + \sigma)\alpha_N}.$$

The first-round effects, due to changes in international food prices, depend on $\Phi_{p_F^*}^{IM}$*, and the weight* $\omega_{p_F^*}$ *is given by:*

$$\omega_{p_F^*} = \frac{1 - \rho_{p_F^*}}{1 - \rho_{p_F^*} + R^* + \gamma v (1 - \alpha_N) - \mathfrak{a}} \in [0, 1).$$

Proof. See the Appendix A. ■

The IM solution in Proposition 3 shows that the first-round pass-through parameter $\Phi_{p_F^*}^{IM}$ is a convex combination of the parameters for CM and FA, with the weight $\omega_{p_F^*}$ pushing toward the CM case—i.e., $\Phi_{p_F^*}^{IM}$ is the weighted sum of the previous two pass-through parameters $\Phi_{p_F^*}^{CM}$ and $\Phi_{p_F^*}^{FA}$. Note, however, that although the IM solution nests as a specific case the FA solution, it does not nest the CM solution—i.e., $\omega_{p_F^*} \in [0, 1)$. This should be clear as one cannot replicate equilibrium allocations of complete markets under incomplete markets. Moreover, the combination of the two solutions reflects two separate channels that are present when markets are incomplete. The first channel captures the inter-temporal substitution effects associated with food shocks. This channel is proportional to the CM solution because it is the only channel present in that specification. The second channel captures the income or wealth effect of the shocks. Similarly, this channel is proportional to the FA solution because it is the only driving channel in that FA specification. And, in contrast to the previous two solutions, when markets are incomplete the country's net foreign asset position affects equilibrium inflation, since $\Phi^{IM}_{b^*} < 0$.

Our analysis suggests that first-round effects are not necessarily proportional to the share of food in the CPI α_F, except for CM. Of course, if the food endowment was equal to zero ($\kappa_F = 0$), then the first-round effects would be proportional to this share even under FA or IM. These specific cases also raise the question of the conditions under which the first-round effects are *exactly* proportional to this share. More specifically, under which conditions are the first-round effects *equal* to the *direct* effect $\alpha_F \Delta \hat{p}^*_{F,t}$? We provide the answer to this question in the following corollary of the previous propositions.

Corollary 1 *The first-round effects $\Phi^j_{p^*_F} \Delta \hat{p}^*_{F,t}$ (for $j = FA, CM, IM$) will be equal to the direct inflationary effect $\alpha_F \Delta \hat{p}^*_{F,t}$ when*

a) *the steady-state food endowment equals a threshold value $\kappa^{DE}_F = \left[1 - \frac{(1+\eta\psi)(1-\alpha_N)+\eta(\psi+\sigma)\alpha_N}{\psi+\sigma}\right] \alpha_F$, under **financial autarky (FA).***

b) *$\eta = \frac{1}{\sigma}$, under **complete markets (CM).***

c) *conditions **a)** and **b)** are satisfied simultaneously, under **incomplete markets (IM).***

Proof. See the Appendix A. ■

Corollary 1 implies several interesting results. Under FA, inflation would increase by the direct effect only when the steady-state food endowment κ_F equals the threshold κ^{DE}_F. Any value of κ_F above κ^{DE}_F implies the inflationary effect will be smaller than the direct effect ($\hat{\pi}^{FA}_t < \alpha_F \Delta \hat{p}^*_{F,t}$). For a broad range of parameter values, unless the elasticity of substitution η is very small ($\eta << 1$, see discussion below), the threshold value κ^{DE}_F will be quite small (much lower than α_F). In other words, the food balance must be in substantial deficit before the inflationary effect is comparable to the direct effect. Under CM, first-round and direct effects will coincide as long as the intratemporal elasticity η equals the intertemporal elasticity of substitution $1/\sigma$. If the intertemporal elasticity is smaller than the intratemporal one ($\eta > 1/\sigma$)—i.e., the three consumption goods are Edgeworth substitutes[16]—then the effect on inflation is smaller than the direct effect ($\hat{\pi}^{CM}_t < \alpha_F \Delta \hat{p}^*_{F,t}$).[17] Finally, under IM, inflation will correspond to the direct effect when the two conditions above—namely $\kappa_F = \kappa^{DE}_F$ and $\eta = \frac{1}{\sigma}$—hold.

C. Remarks

We now provide a brief discussion of how other structural parameters affect the pass-through parameters $|\Phi^{FA}_{p^*_F}|$—the sign of which depends on the country's food balance—and $\Phi^{CM}_{p^*_F}$. We also discuss

[16] See Svensson and van Wijnbergen (1989).

[17] Of course, the opposite holds if the intertemporal elasticity is bigger than the intratemporal one ($1/\sigma > \eta$)—i.e., the three consumption goods are Edgeworth complements.

how these structural parameters affect the weight $\omega_{p_F^*}$ associated with the IM solution.

- The higher the elasticity of substitution between goods (η), the easier it is for agents to switch expenditure. In this case, the relative price of non-traded goods $\hat{p}_{N,t}$ needs to fall by less and therefore $\partial|\Phi_{p_F^*}^{FA}|/\partial\eta < 0$ and $\partial\Phi_{p_F^*}^{CM}/\partial\eta < 0$. By reducing the impact of the shock on aggregate consumption under financial autarky, the higher elasticity of substitution also reduces the marginal value of accumulating net foreign assets. As a result, it brings the IM solution closer to financial autarky: $\partial\omega_{p_F^*}/\partial\eta < 0$.

- Under FA, the relative risk aversion coefficient σ—the inverse of the intertemporal elasticity of substitution—affects internal balance only. A higher σ makes labor supply more sensitive to a fall in consumption. For a given decline in consumption, say from an increase in international food prices $\hat{p}_{F,t}^*$, internal balance then requires a larger, offsetting, fall in wages $\hat{w}_t$. Since $\hat{p}_{N,t} = \hat{w}_t$ inflation increases by more: $\partial|\Phi_{p_F^*}^{FA}|/\partial\sigma > 0$. Under CM, σ also affects external balance, as it reduces the consumer's willingness to reduce consumption $\hat{c}_t$ temporarily in response to an increase in the price of the basket (since $1/\sigma$ is the inter-temporal elasticity of substitution). The latter effect dominates, so $\partial\Phi_{p_F^*}^{CM}/\partial\sigma < 0$. A higher σ also increases the marginal value of accumulating net foreign assets an therefore brings the IM solution closer to the complete markets case. Then $\partial\omega_{p_F^*}/\partial\sigma > 0$.

- A higher ψ—the inverse of the Frisch elasticity—has two offsetting effects. On the one hand, it makes labor supply less sensitive to wages $\hat{w}_t$—which results in larger movements in real wages to clear the labor markets. On the other hand, it makes labor supply less sensitive to movements in consumption $\hat{c}_t$—which results in smaller offsetting movements in real wages when consumption falls. If $\eta > 1/\sigma$, the second channel dominates and a smaller decrease in real wages—and also in $\hat{p}_{N,t}$ since $\hat{p}_{N,t} = \hat{w}_t$—is required. Inflation increases by less: $\partial|\Phi_{p_F^*}^{FA}|/\partial\psi < 0$ and $\partial\Phi_{p_F^*}^{CM}/\partial\psi < 0$. Also when $\eta > 1/\sigma$, a higher ψ increases the effect of the shock on consumption (under FA), thus raising the marginal value of accumulating net foreign assets. As a result, the IM solution gets closer to the CM case, implying that $\partial\omega_{p_F^*}/\partial\psi > 0$.[18]

- A larger non-traded sector (higher α_N) has two offsetting effects on the bop. On the one hand, it increases total consumption's sensitivity to changes in the relative price of non-traded goods $\hat{p}_{N,t}$, to satisfy external balance, which reduces pressures on $\hat{p}_{N,t}$. On the other hand, it increases consumption's exposure to international food prices $\hat{p}_{F,t}^*$, which increases pressures on $\hat{p}_{N,t}$ (also to satisfy external balance). Under FA, the first effect dominates when $\eta > 1/\sigma$ implying that $\hat{p}_{N,t}$ decreases by less, so $\partial|\Phi_{p_F^*}^{FA}|/\partial\alpha_N < 0$. The opposite holds under CM, i.e., $\partial\Phi_{p_F^*}^{CM}/\partial\alpha_N > 0$. A larger α_N brings the IM solution closer to the CM case and hence $\partial\omega_{p_F^*}/\partial\alpha_N > 0$. [19]

- A higher autocorrelation of international food price shocks $\rho_{p_F^*}$ has no effect on $\Phi_{p_F^*}^{FA}$ or $\Phi_{p_F^*}^{CM}$. However, by increasing the persistence of international food prices $\hat{p}_{F,t}^*$, it increases the wealth effect from changes in this variable, thus increasing the relative importance of the FA solution in the IM case: $\partial\omega_{p_F^*}/\partial\rho_{p_F^*} < 0$.

[18] As before if instead $1/\sigma > \eta$ then $\partial|\Phi_{p_F^*}^{FA}|/\partial\psi > 0$, $\partial\Phi_{p_F^*}^{CM}/\partial\psi > 0$ and $\partial\omega_{p_F^*}/\partial\psi < 0$.

[19] If instead $1/\sigma > \eta$ then $\partial|\Phi_{p_F^*}^{FA}|/\partial\alpha_N > 0$ and $\partial\Phi_{p_F^*}^{CM}/\partial\alpha_N < 0$, but $\partial\omega_{p_F^*}/\partial\psi \lesseqgtr 0$.

- A higher portfolio adjustment cost υ also has no effect on $\Phi^{FA}_{p^*_F}$ or $\Phi^{CM}_{p^*_F}$. But by increasing the costs associated with inter-temporal smoothing, it reduces the relative importance of the CM solution in the IM case, so $\partial\omega_{p^*_F}/\partial\upsilon < 0$.

- A lower interest rate R^* reduces the annuity value from future income. It therefore lowers the wealth effects associated with a food shock, bringing the IM solution closer to complete markets. Then $\partial\omega_{p^*_F}/\partial R^* < 0$.

IV. Calibration and a Graphic Representation

We now quantify the first-round effects of shocks to $\hat{p}^*_{F,t}$ under various calibrations of the model. Throughout these simulations we keep all parameters constant, with the exception of the food endowment κ_F.

A. Calibration

We do not calibrate the model to a specific country but draw instead on evidence from the universe of developing countries. Our choice of parameters is summarized in Table 1.

Table 1: Benchmark Calibration

α_F	α_N	σ	η	ψ	β	υ	$\rho_{p^*_F}$
0.5	0.3	3	1	5	0.99	0.1875	0.87

Our benchmark calibrations is justified as follows. The average share of food in the CPI in sub-Saharan African countries is 48.5 percent, so we pick $\alpha_F = 0.5$.[20] In a group of 3 African countries (Kenya, Ghana, Uganda) the share of non-traded goods and services (housing, health, education, recreation, transportation and communication) is 33 percent on average (we pick $\alpha_N = 0.3$).[21] We calibrate σ from Ogaki, Ostry and Reinhart (1997), who estimate the inter-temporal elasticity of substitution for developing countries: their average estimate is 0.337, which implies $\sigma \simeq 3$. We infer ψ from Goldberg (2011), who estimates the wage elasticity in the day labor market in rural Malawi. She finds an elasticity of $0.15 - 0.17$. While her estimate is not directly applicable to our specification—she focuses on the extensive margin of labor supply—we set $\psi = 5$, which implies a Frisch elasticity of 0.2. The choice of the intertemporal discount rate is standard in the literature.

[20] See IMF (2011).

[21] On Uganda, see "Consumer Price Index April 2001," available at www.ubos.org. On Ghana see "Time Series P1," available at www.statsghana.gov.gh. On Kenya see "CPI December 2008," available at www.knbs.or.ke/consumerpriceindex.php.

Two parameter choices are worth discussing in some detail. First, we draw η from Seale et al. (2003), who estimate compensated own-price elasticity for food and beverages. Their average estimate for the 40 countries with the lowest income per capita in their sample is slightly lower than -0.5, which implies $\eta \simeq 1$. This value is higher than elasticities used in other studies (see Anand and Prasad, 2010) so we will consider alternative values below. Second, we draw on Akitoby and Stratmann (2008) to calibrate v. These authors regressed interest rate spreads in emerging markets on a number of various gross external assets and liabilities (and policy variables). When combined to form a net asset value, their estimates imply a relatively low value of v ($v = 0.1875$). We believe their estimate provides a lower bound on the value of v in low income countries, which is likely to be much higher as many of these countries do not even have access to international capital markets (and would therefore be excluded from their sample of countries). However, we will use this value as a starting point and discuss alternative values later.

Finally, we pick $\rho_{p_F^*}$ using data on an international food price index compiled at the IMF, deflated by the US CPI.[22] We extract the business cycle component using a band pass filter, and find that the sample autocorrelation is 0.87.[23] We will also experiment with other parameter values below.

B. Graphic Representation

The inflationary impact of a 1 percent increase in $\Delta \hat{p}_F^*$ is represented in Figure 1. The figure plots the impact on inflation against the country's net food deficit ($\alpha_F - \kappa_F$). The straight black line represents the inflationary impact under financial autarky $\Phi_{p_F^*}^{FA}$, the dashed-dotted line represents the inflationary impact under complete markets $\Phi_{p_F^*}^{CM}$, and the straight grey line represents the impact under incomplete markets $\Phi_{p_F^*}^{IM}$. The dashed line represents the direct effect α_F.

As previously discussed, the inflationary impact under CM does not depend on κ_F. Under our calibration $\eta > 1/\sigma$, which implies this case generates an increase in inflation that is smaller than the direct effect ($\Phi_{p_F^*}^{CM} = 0.27 < \alpha_F$). On the other hand, the impact under FA ranges from -0.24 percent when the country's endowment of food is 70 percent (the highest possible value for κ_F) to 0.61 percent when $\kappa_F = 0$. The FA solution coincides with complete markets when $\kappa_F = 0.28$ (point b in the figure). This is the value of κ_F for which the complete markets solution is associated with ex-post balanced (overall) trade. The FA solution coincides with the direct effect when $\kappa_F = 0.0875$ (point c).

The IM solution is closer to the FA solution: under the current calibration, the weight on the CM case $\omega_{p_F^*}$ is less than one third ($\omega_{p_F^*} = 0.32$). By construction the IM solution matches both FA and CM at point b.

While the FA and IM solutions provide a range of possible first-round effects, we need to discipline the choice of κ_F to provide a quantitative estimate. We therefore draw on trade data from a sample of 28 sub-Saharan countries, for the period 2000-2006. The median food balance in this sample was a

[22] The data is available at http://www.imf.org/external/np/res/commod/index.aspx.
[23] See Baxter and King (1999).

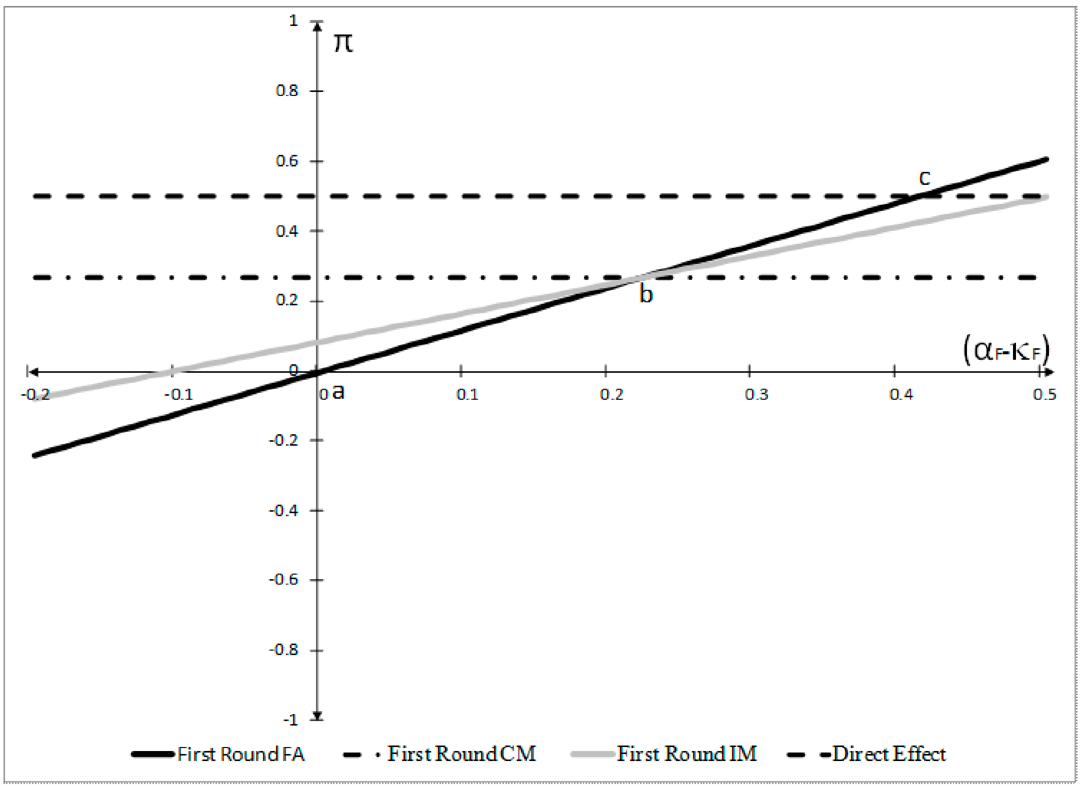

Figure 1: First-Round Effects: Financial Autarky (FA), Complete (CM) and Incomplete Markets (IM).

deficit of 0.9 percent of GDP, with the highest food deficit being 10.12 percent and the highest food surplus being 14.12 percent.[24] In our model this implies a median food endowment $\kappa_F = 0.481$, with a range of $(0.389, 0.641)$. In this case, the median inflationary effect predicted under FA is 0.01 percent, with a range of $(-0.17, 0.12)$. Under incomplete markets, the median is 0.09 percent, with a range of $(-0.03, 0.17)$.

C. Sensitivity Analysis

Varying the Intra-temporal Elasticity of Substitution η

While the baseline calibration has drawn on empirical work using data from developing countries, there is considerable uncertainty over possible parameter values, and other calibrations are also possible. In particular, it can be argued that the elasticity of substitution between food and non-food items is lower than one, reflecting the view that poor households may be severely limited in their ability to substitute away from food consumption. For this reason, we now explore how results change when η goes from 1 to 0.1.

The inflationary first-effect impact from a 1 percent increase in $\Delta\hat{p}_F^*$ is now represented in Figure 2. The impact under FA is represented with a black dotted line, the impact under CM is represented with a long dashed-dotted line, and the impact under IM is represented with a grey dotted line. We have also included the previous first-effect lines for $\Phi_{p_F^*}^{FA}$, $\Phi_{p_F^*}^{CM}$, and $\Phi_{p_F^*}^{IM}$ associated with $\eta = 1$ (black straight, dashed-dotted, and grey straight lines, respectively).

When η falls below $1/\sigma$, which is the case here, the goods become Edgeworth-Pareto complements. In this case, the line for $\Phi_{p_F^*}^{CM}$ shifts up, and the inflationary first-effect impact jumps above the direct effect: $\Phi_{p_F^*}^{CM} = 0.72 > \alpha_F$.

Under FA, instead, the line for $\Phi_{p_F^*}^{FA}$ rotates, becoming steeper. While a net food balance still implies zero inflation, food deficits now lead to larger inflationary pressures. The median food balance from the sample of African countries (0.9 percent of GDP) is now associated with an increase in inflation of 0.055 percent. With the highest food deficit in the sample (10.12 percent of GDP), the increase in inflation is now 0.62 percent, above the direct effect. The flip side is that food surpluses now result in larger deflations: the highest food surplus in the sample (14.12 percent of GDP) is now associated with a deflation of -0.87 percent!

With IM, the line for $\Phi_{p_F^*}^{IM}$ shifts up and become steeper. The inflationary impact of food price increases is now greater over a large range of food balances, but it also becomes deflationary at a faster rate following some threshold food surplus. The median food balance in the sample is now associated with an increase in inflation of 0.29 percent, with a range $(-0.24, 0.66)$.

[24] Data is available on http://wits.worldbank.org. We define food trade as consisting of the following categories: live animals except fish, meat and preparations, dairy products and eggs, fish/shellfish, cereals/cereal preparation, vegetables and fruit, sugar/sugar/honey, coffee/tea/cocoa/spices, animal feed, miscellaneous food products, beverages, tobacco/manufactures, oil seeds/oil fruits, crude animal/vegetable matters, animal/vegetable oil/fat/wax.

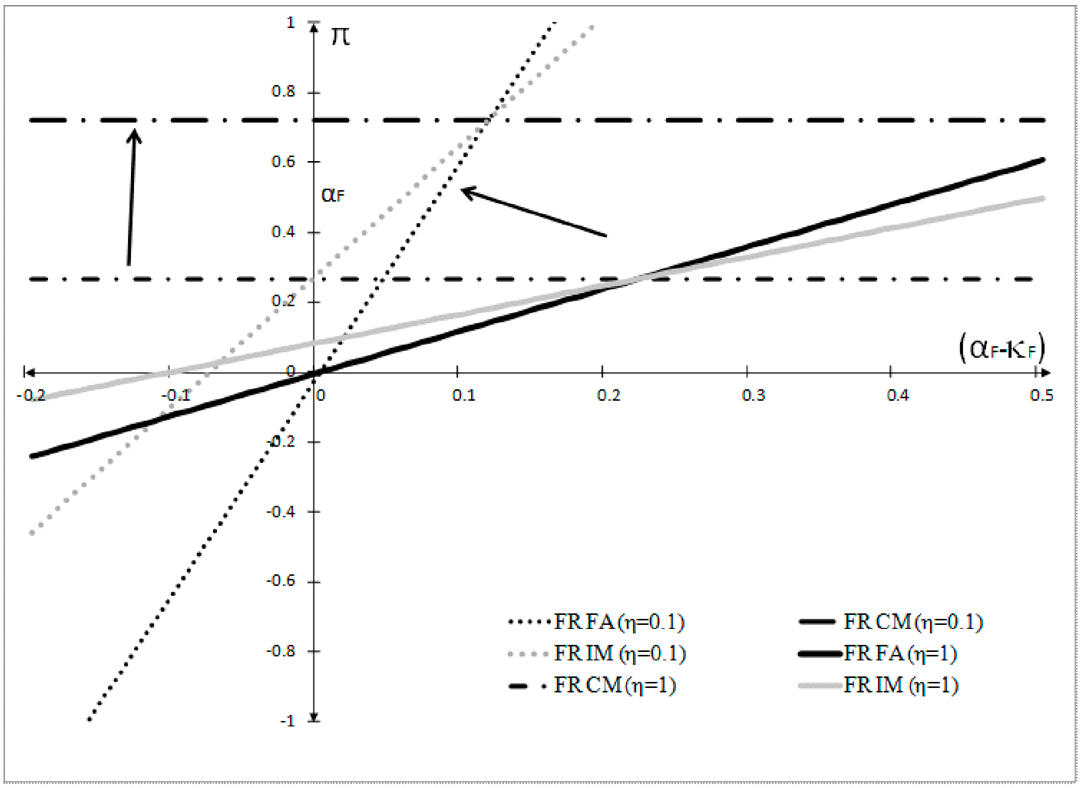

Figure 2: First-Round Effects: Varying the Intra-temporal Elasticity of Substitution ($\eta = 1$ vs. $\eta = 0.01$).

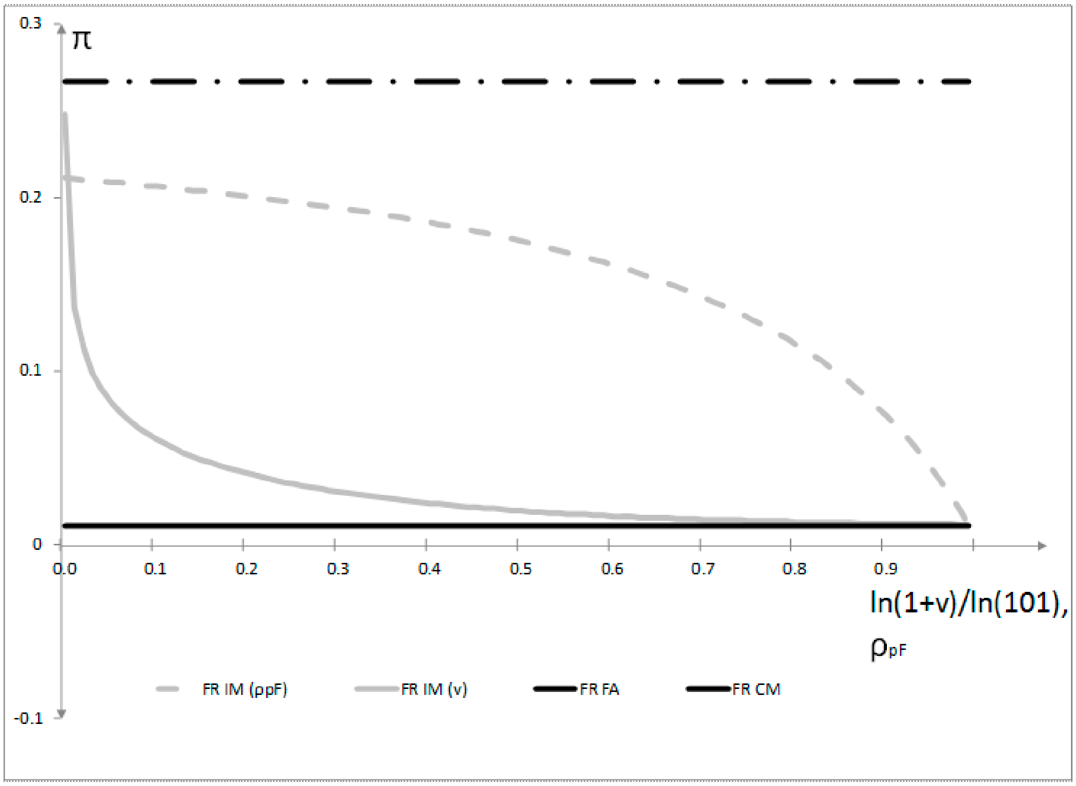

Figure 3: First-Round Effects: Varying the Portfolio Adjustment Costs Parameter v and the Persistence of International Food Prices $\rho_{p_F^*}$.

In sum, lower elasticities of substitution lead to higher first-effect inflation rates in a number of cases (complete markets, financial autarky when the food balance is in deficit, incomplete market under food deficits and a range of food surpluses). However, they also result in larger deflations in other cases (under FA when the country is a net food exporter, and under IM over a threshold food balance value).

Varying the Portfolio Adjustment Costs Parameter v

We now explore what happens when portfolio adjustment costs v vary. Figure 3 displays $\Phi_{p_F^*}^{CM}$ and $\Phi_{p_F^*}^{FA}$ under the median food balance in the sample. It also displays values of $\Phi_{p_F^*}^{IM}$ as the portfolio adjustment costs increases (using a log scale). As previously discussed, the IM solution approximates the FA solution as v increases. Concretely, a doubling of v from 0.1875 to 0.375, which is a relatively small adjustment, lowers $\omega_{p_F^*}$ (the weight of the CM solution) from 0.32 to 0.24. A tripling of v lowers $\omega_{p_F^*}$ to 0.20.

Varying the Persistence of the International Food Prices $\rho_{p_F^*}$

Figure 3 also displays values of $\Phi_{p_F^*}^{IM}$ as $\rho_{p_F^*}$ increases. Note that, as $\rho_{p_F^*}$ approaches one, small changes in this parameter bring the IM solution increasingly closer to the FA case. Concretely, raising

$\rho_{p_F^*}$ from 0.87 to 0.9 lowers $\omega_{p_F^*}$ from 0.32 to 0.24. Setting $\rho_{p_F^*} = 0.95$ lowers $\omega_{p_F^*}$ to 0.15.

V. Extension: Incomplete Tradability of the Food Basket

So far, we have assumed the food basket is fully tradable. We now explore how our first-round-effect results change when the assumption of complete tradability is relaxed.[25] We focus on the extreme cases of financial autarky and complete markets, for simplicity.

Food consumption is now a basket, with two items:

$$c_{F,t} = \left[\varsigma^{\frac{1}{\eta}} c_{FT,t}^{\frac{\eta-1}{\eta}} + (1-\varsigma)^{\frac{1}{\eta}} c_{FN,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}.$$

$c_{FT,t}$ and $c_{FN,t}$ are the consumption of traded and non-traded food, respectively, with nominal prices $(P_{FT,t}, P_{FN,t})$. ς measures the share that is tradable. A unit value for ς corresponds to the original version of the model, which we will refer to as the baseline. For simplicity the elasticity of substitution is assumed the same as that between food and non-food (η). Utility maximization results in the standard demand equations:

$$c_{FT,t} = \varsigma \left(\frac{p_{FT,t}}{p_{F,t}} \right)^{-\eta} c_{FT,t} = \varsigma \alpha_F p_{FT,t}^{-\eta} c_t, \tag{32}$$

and

$$c_{FN,t} = (1-\varsigma) \left(\frac{p_{FN,t}}{p_{F,t}} \right)^{-\eta} c_{FT,t} = (1-\varsigma) \alpha_F p_{FN,t}^{-\eta} c_t, \tag{33}$$

where we have made use of equation (7). The terms $p_{FT,t}$ and $p_{FN,t}$ denote relative prices of traded and non-traded food, which are now combined to create a relative price index for food:

$$p_{F,t} = \left[\varsigma p_{FT,t}^{1-\eta} + (1-\varsigma) p_{FN,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}. \tag{34}$$

A similar equation holds for the nominal price of food $(P_{F,t})$.

The representative agent now has two food endowments: (y_{FT}, y_{FN}). In the non-traded case, consumption must equal the endowment: $c_{FN,t} = y_{FN}$, with the price $p_{FN,t}$ adjusting to ensure equilibrium. In the traded case, instead, the price $p_{FT,t}$ is given by the law of one price: $p_{FT,t} = s_t p_{F,t}^*$. The central bank is still assumed to have the technology to perfectly stabilize the inflation of sticky-price non-traded goods.

The steady state is similar to that in the baseline case, with $p_{FN} = 1$ and $y_{FT} + y_{FN} = \kappa_F$. The non-traded food endowment must equal $(1-\varsigma)\alpha_F$, which implies $y_{FT} = \kappa_F - (1-\varsigma)\alpha_F$. This condition and the constraint that the endowment of traded food cannot be negative place a lower bound

[25] Trade costs may render certain staples effectively non-tradable within a certain price band (see Bergin and Glick, 2009). Trade restrictions have similar effects. Non-tradability may be endogenous, with large changes in international prices increasing the tradability of certain food items. For simplicity, we treat tradability in food as exogenous.

on possible values of ς. The larger the steady-state trade deficit in food $(\alpha_F - \kappa_F)$, the larger the lower bound on the share of traded food in consumption: $\varsigma \in (\bar{\varsigma}, 1)$, with $\bar{\varsigma} = max\{0, (\alpha_F - \kappa_F)/\alpha_F\}$. Intuitively, a country that relies on imports to secure its food consumption must have a large share of traded food in its basket.

A. Analytical Solution Under Incomplete Food Tradability

As before, we log-linearize the model around the steady state. As in the baseline case, we can reduce the model to two equations. The internal balance equation is the same as before—see equation (22)—since conditions in the non-traded goods market and the labor market—equations (3), (6), (15) and (16) have not changed. Then

$$\hat{c}_t = \frac{1 + \eta\psi}{\psi + \sigma} \hat{p}_{N,t}.$$

The second equation corresponds to a "revised" external balance condition, which now incorporates two equilibrium conditions and it varies depending on the international asset market structure.

Financial Autarky (FA)

Under FA, the external balance equation can be derived by combining the clearing of the balance of payments with the equilibrium in the non-traded food market—this requires the log-linearized versions of equations (7), (8), (9), (11), (19), (32), (33), and (34). The new external balance condition is the same as before:[26]

$$\hat{c}_t = -\frac{\alpha_N \eta}{1 - \alpha_N} \hat{p}_{N,t} - \frac{\alpha_F - \kappa_F}{1 - \alpha_N} \hat{p}^*_{F,t}.$$

Intuitively, the impact of international food prices on the balance of payments still depends on whether the country is a net food importer or exporter, independently of how large the share of traded food (ς) is. While there is a link between possible values for ς and the net food balance of the country (see above discussion), the balance contains all the necessary information about the structure of the food market to study the aggregate macroeconomic adjustment to food shocks.

With FA, since the equations that describe internal and external balance remain unchanged, the inflationary effect of the two shocks $(\hat{p}^*_{F,t},\ \hat{y}_{F,t})$ is the same as before when food was fully tradable. We state this result as a proposition without a proof.

Proposition 4 *Under* ***financial autarky (FA)*** *and incomplete food tradability, if the elasticities of substitution (η) between food types and between food and non-food are the same, then the equilibrium for inflation is the same as that when food is fully tradable, as described by equation (29).*

The proposition implies that, under FA and when food is partially tradable, the first-round effects are *still* proportional to the food balance $(\alpha_F - \kappa_F)$. However, an important difference concerns the

[26] Relaxing the restriction that the elasticity of substitution between food and non-food is the same as the elasticity of substitution between different types of food does not change this result. The proof is available upon request.

nominal price that implements the required increase in inflation. In the baseline specification, only the nominal exchange rate $\Delta\hat{S}_t$ adjusts. In the extension, we can combine equations (9), (10), and (34) to obtain the following relation:

$$\hat{\pi}_t^{FA} = \alpha_F\varsigma\Delta\hat{p}^*_{F,t} + (1-\alpha_N-\alpha_F(1-\varsigma))\,\Delta\hat{S}_t^{FA} + \alpha_F(1-\varsigma)\hat{\pi}^{FA}_{FN,t},$$

where $\hat{\pi}^{FA}_{FN,t} = log(P_{FN,t}) - log(P_{FN,t-1})$. For a given $\Delta\hat{p}^*_{F,t}$, equilibrium changes in inflation must therefore come from either $\Delta\hat{S}_t^{FA}$ or $\hat{\pi}^{FA}_{FN,t}$, i.e., changes in the nominal price of non-traded food. To understand when and how each nominal price adjusts, we solve for the equilibrium changes in non-traded food inflation by combining equations (22), (29), (33) and the identity $\hat{\pi}^{FA}_{FN,t} = \Delta\hat{p}^{FA}_{FN,t} + \hat{\pi}_t^{FA}$. The solution for $\hat{\pi}^{FA}_{FN,t}$ is the following:

$$\hat{\pi}^{FA}_{FN,t} = \Gamma^{FA}_{p_F^*}\Delta\hat{p}^*_{F,t},$$

with

$$\Gamma^{FA}_{p_F^*} = \frac{(\eta\sigma-1)(\alpha_F-\kappa_F)}{\eta\left[(1+\eta\psi)(1-\alpha_N)+\eta(\psi+\sigma)\alpha_N\right]}.$$

If $\eta > 1/\sigma$, the effect of $\Delta\hat{p}^*_{F,t}$ on non-traded food inflation has the same sign as that of the food trade deficit $(\alpha_F-\kappa_F)$. As before, we can distinguish three cases. When food trade is balanced, non-traded food inflation does not change ($\hat{\pi}^{FA}_{FN,t} = 0$), which implies the nominal exchange rate appreciation is solely responsible for keeping overall inflation constant: $\Delta\hat{S}^{FA} = -\alpha_F\varsigma/\left[1-\alpha_N-\alpha_F(1-\varsigma)\right]\Delta\hat{p}^*_{F,t}$. If the food trade is in deficit (surplus), then non-food traded inflation also increases (decreases) with changes in $\Delta\hat{p}^*_{F,t}$.

Complete Markets (CM)

Under CM, the revised external balance assumption now combines the risk sharing condition with the equilibrium in the non-traded food market—this requires all the equations (9), (20), (32), (33), and (34). In this case, the external balance condition is the following:

$$\hat{c}_t = -\vartheta_{p_N}\hat{p}_{N,t} - \vartheta_{p_{F^*}}\hat{p}^*_{F,t}, \tag{35}$$

with

$$\vartheta_{p_N} = \frac{\alpha_N\eta}{\eta\sigma(1-\alpha_N)-\alpha_F(1-\varsigma)(\eta\sigma-1)} \quad \text{and} \quad \vartheta_{p_{F^*}} = \vartheta_{p_N}\frac{\alpha_F\varsigma}{\alpha_N}.$$

This new condition merits two comments. First, it reduces to the previous external balance condition—see equation (24)—if food is fully tradable ($\varsigma = 1$). Second, the impact of food prices $\hat{p}^*_{F,t}$ on consumption $\hat{c}_t$ is now proportional to the share of traded food in consumption ($\alpha_F\varsigma$), rather than the total share of food (α_F) as was the case before.

Combining (22) with (28) and (35) yields the equilibrium solution for inflation, from which we can infer the first-round effects. We can state our extended result as a proposition without a proof.

Proposition 5 *Under* ***complete markets (CM)*** *and incomplete food tradability, if the elasticities of substitution (η) between food types and between food and non-food are the same, then equilibrium inflation is given by:*

$$\hat{\pi}_t^{CM,FN} = \Phi^{CM,FN}_{p_F^*}\Delta\hat{p}^*_{F,t}$$

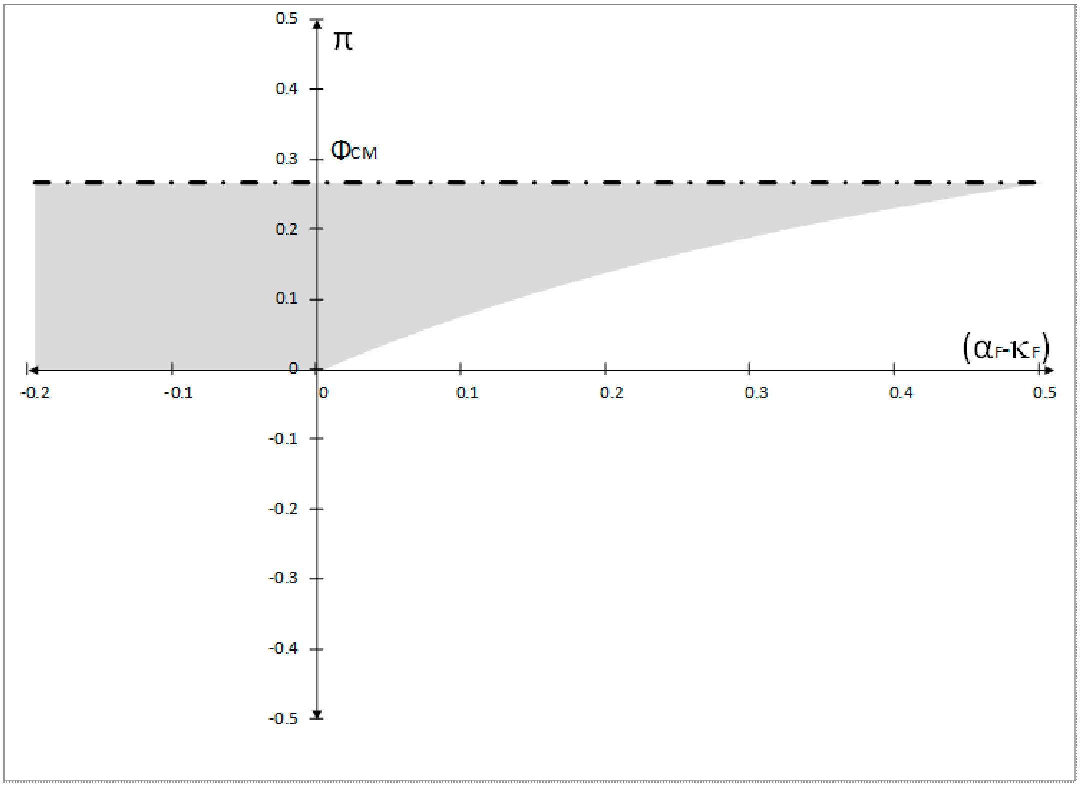

Figure 4: First-Round Effects: Varying the Tradable Food Share (ς).

with

$$\Phi_{p_F^*}^{CM,FN} = \left[\frac{(\psi+\sigma)\eta}{(1+\eta\psi)(\eta\sigma(1-\alpha_N)-\alpha_F(1-\varsigma)(\eta\sigma-1))+(\psi+\sigma)\alpha_N\eta}\right]\alpha_F\varsigma,$$

and where the first-round effects depend on $\Phi_{p_F^*}^{CM,FN}$.

Under CM and incomplete food tradability, the new external balance condition implies that the inflationary effect of shocks to $\hat{p}_{F,t}^*$ is proportional to the share of traded food ($\alpha_F\varsigma$), rather than the full share (α_F). If $\varsigma < 1$, it is always the case that $\Phi_{p_F^*}^{CM,FN} < \Phi_{p_F^*}^{CM}$. In other words, changes in foreign food prices now have a smaller effect on inflation, relative to the case of complete food tradability. Figure 4 shows possible values for $\Phi_{p_F^*}^{CM,NF}$, for the range of admissible values of ς (the shaded area under the dash-dotted line). As the food deficit becomes positive and begins to increase, the range of possible values for $\Phi_{p_F^*}^{CM,NF}$ becomes gradually smaller.

Overall, we can conclude that incomplete food tradability does not significantly affect our previous results on the first-round effects.

VI. Conclusions

We developed a tractable small open economy model to study the first-round effects of international food price shocks in developing countries. We have shown that first-round effects—changes in headline inflation that, holding core inflation constant, help implement relative price adjustments—depend crucially on the asset market structure. Under complete markets, these effects are proportional to the share of food in the CPI; under financial autarky, they are instead proportional to the country's food balance. In developing countries the former are large and the latter are small, which implies large variations in first-round effects across asset market structures. Incomplete markets yield a combination of these two extremes. Our results cast some doubt on the view that international food price shocks are inherently inflationary in developing countries, as it can be argued that these countries are closer to financial autarky than they are to complete markets.

We believe our model-based exercise has helped provide a clear definition of the concept of first-round effects. As the discussion in the paper makes clear, stating such definition is considerably more challenging in the absence of a clear analytical framework. Although the inflationary effect of international food price shocks is ultimately an empirical question, there are limits to what the data can reveal about first-round effects. This is because it is in practice very difficult to empirically disentangle first- and second-round effects and the monetary policy response. In fact, we are not aware of any robust empirical work that has disentangled and estimated these effects.[27] In this regard, our approach might help inform and complement future work based on purely empirical approaches.

Two possible caveats emerge, however, in our analysis. First, we have assumed a homogeneous traded food category, which excludes the possibility of changes to the food terms of trade (the ratio of food export prices to food import prices). But this may not be the case; even if food balances are small on average, international food price shocks may lead to changes in the food terms of trade. Under financial autarky, the latter would then amplify the income effects associated with the shock, and its inflationary impact. Second, we have assumed a representative agent and an associated price index/consumer basket. In practice, there may be important differences between the urban and rural sector, which may be thought of as two separate and possibly segmented regions within a country. In this case, an international food price shock may have larger effects on relative food prices faced by urban households, even if the country's overall food balance is small. If consumer price indices in developing country tend to reflect urban prices, then this may lead to larger (measured) inflationary effects from these shocks. We leave the analysis of these alternative assumptions for future work.

[27] There are some works that, without disentangling these effects, have tried to relate the overall inflationary impact of commodity price shocks to a broad range of structural characteristics and policy frameworks, across countries. See for instance, Gelos and Ustyugova (2012).

A Appendix

A. Proofs of Propositions and Corollaries

A.1. Proof of Proposition 1

Proof. Combine (22) and (23) to derive

$$\hat{p}_{N,t} = -\left[\frac{(\psi+\sigma)(\alpha_F-\kappa_F)}{(1+\eta\psi)(1-\alpha_N)+\eta(\psi+\sigma)\alpha_N}\right]\hat{p}^*_{F,t}. \tag{A.1}$$

Note that uniqueness follows from the facts that (22) and (23) are, respectively, strictly increasing and strictly decreasing in $\hat{p}_{N,t}$. Using (28) and (A.1), we can solve for $\hat{\pi}_t^{FA}$ in terms of $\Delta\hat{p}^*_{F,t}$ and obtain (29). ■

A.2. Proof of Proposition 2

Proof. Combine (22) and (24) to derive

$$\hat{p}_{N,t} = -\left[\frac{(\psi+\sigma)\alpha_F}{(1+\eta\psi)(1-\alpha_N)\sigma+(\psi+\sigma)\alpha_N}\right]\hat{p}^*_{F,t}. \tag{A.2}$$

Note that uniqueness follows from the facts that (22) and (24) are, respectively, strictly increasing and strictly decreasing in $\hat{p}_{N,t}$. Using (28) and (A.2), we can solve for $\hat{\pi}_t^{CM}$ in terms of $\Delta\hat{p}^*_{F,t}$ and obtain (30). ■

A.3. Proof of Proposition 3

Proof. The proof has two parts. First we prove the existence of a unique equilibrium (stability). Second we apply the method of undetermined coefficients to derive the analytical solution.

To prove equilibrium uniqueness, we rewrite equations (22), (25) and (26) as the system

$$E_t\widehat{x}_{t+1} = \Psi\widehat{x}_t + \Upsilon\hat{p}^*_{F,t}, \tag{A.3}$$

where $\widehat{x}_t = [\hat{p}_{N,t}, \hat{b}^*_{t-1}]'$,

$$\Psi = \begin{bmatrix} 1+\gamma v(1-\alpha_N) & -\tau v(1-\alpha_N)R^* \\ -\vartheta^{-1} & R^* \end{bmatrix},$$

$$\gamma \equiv \frac{\tau}{\vartheta}, \qquad \vartheta = \frac{(\psi+\sigma)}{(1+\eta\psi)(1-\alpha_N)+(\psi+\sigma)\alpha_N\eta}, \qquad \tau = \frac{(\psi+\sigma)}{(1+\eta\psi)(1-\alpha_N)\sigma+(\psi+\sigma)\alpha_N},$$

and the form of Υ is omitted since it is not required for the stability analysis. The characteristic polynomial associated with Ψ is given by

$$\mathcal{P}(\mathfrak{a}) = \mathfrak{a}^2 - [1+R^*+\gamma v(1-\alpha_N)]\,\mathfrak{a} + R^* \tag{A.4}$$

satisfying

$$\mathcal{P}(1) = -\gamma v(1-\alpha_N) < 0 \qquad \text{and} \qquad \mathcal{P}(-1) = 2(1+R^*) + \gamma v(1-\alpha_N) > 0.$$

Since $\mathcal{P}(1) < 0$ and $\mathcal{P}(-1) > 0$ then following Azariadis (1993) we can infer that both eigenvalues of Ψ, i.e., $\mathfrak{a}_1$ and $\mathfrak{a}_2$, are on the same side of -1 and on different sides of 1. The only possibility is that one eigenvalue is in $(-1,1)$ and the other one in $(1,\infty)$. Thus the steady state is a saddle. Without loss of generality, assume that $\mathfrak{a}_2$ is the explosive eigenvalue—i.e., $\mathfrak{a}_2 \in (1,\infty)$—while $\mathfrak{a}_1$ is non-explosive—i.e., $\mathfrak{a}_1 \in (-1,1)$. Then, since there is one non-predetermined variable, $\hat{p}_{N,t}$, and one predetermined variable $\hat{b}^*_{t-1}$, we can use the results by Blanchard and Kahn (1980) to conclude that there exists a unique rational expectations equilibrium for $\{\hat{p}_{N,t},\ \hat{b}^*_{t-1}\}$. Using this and (28) we can also conclude that there is a unique equilibrium for $\hat{\pi}_t$.

To obtain the analytical solutions for $\hat{\pi}_t$ we combine equations (22), (25), (26) and (27) and rewrite the model as the system

$$\Theta\widehat{x}_t = \Omega E_t\widehat{x}_{t+1} + \Gamma\widehat{x}_{t-1} + \Pi\hat{p}^*_{F,t}, \tag{A.5}$$

where *now* $\widehat{x}_t = [\hat{p}_{N,t}, \hat{b}^*_t]'$, while

$$\Theta = \begin{bmatrix} 1 & -\tau v(1-\alpha_N) \\ 1 & \vartheta \end{bmatrix}, \qquad \Omega = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}, \qquad \Gamma = \begin{bmatrix} 0 & 0 \\ 0 & \vartheta R^* \end{bmatrix},$$

and

$$\Pi = \begin{bmatrix} -\tau\alpha_F(1-\rho_{p^*_F}) \\ -\vartheta(\alpha_F - \kappa_F) \end{bmatrix}.$$

Following the undetermined coefficient methods (see Christiano, 2002), the Minimal State Variable (MSV) representation of the solution corresponds to

$$\hat{p}_{N,t} = \mathfrak{d}\hat{b}^*_{t-1} + \mathfrak{e}\hat{p}^*_{F,t} \quad \text{and} \quad \hat{b}^*_{t-1} = \mathfrak{a}\hat{b}^*_{t-1} + \mathfrak{c}\hat{p}^*_{F,t}, \tag{A.6}$$

and it can be written in a compact form as:

$$\widehat{x}_t = \mathcal{A}\widehat{x}_{t-1} + \mathcal{B}\hat{p}^*_{F,t} \qquad \text{and} \qquad \hat{p}^*_{F,t} = \rho_{p^*_F}\hat{p}^*_{F,t-1} + \epsilon_{p^*_F,t}, \tag{A.7}$$

with

$$\mathcal{A} = \begin{bmatrix} 0 & \mathfrak{d} \\ 0 & \mathfrak{a} \end{bmatrix}, \quad \text{and} \quad \mathcal{B} = \begin{bmatrix} \mathfrak{e} \\ \mathfrak{c} \end{bmatrix}.$$

Iterating forward the MSV (A.7) and using it to eliminate all the forecasts $E_t\widehat{x}_{t+1}$ as well as $\widehat{x}_t$ in the model (A.5), we obtain

$$\left[\Omega\mathcal{A}^2 - \Theta\mathcal{A} + \Gamma\right]\widehat{x}_{t-1} + \left[\Omega\mathcal{A}\mathcal{B} + \rho_{p^*_F}\Omega\mathcal{B} - \Theta\mathcal{B} + \Pi\right]\hat{p}^*_{F,t} = 0,$$

which defines the following mappings:

$$\Omega\mathcal{A}^2 - \Theta\mathcal{A} + \Gamma = \mathbf{0} \qquad \text{and} \qquad \Omega\mathcal{A}\mathcal{B} + \rho_{p^*_F}\Omega\mathcal{B} - \Theta\mathcal{B} + \Pi = \mathbf{0}. \tag{A.8}$$

These mappings define a set equations for the elements of the matrices $\mathcal{A}$ and $\mathcal{B}$. In particular, $\mathfrak{a}$ has to solve a quadratic equation $\mathcal{P}(\mathfrak{a}) = 0$, where $\mathcal{P}(\mathfrak{a})$ is the same as the polynomial defined in (A.4). From our stability analysis we know that the steady state is a saddle, while from (A.6) we know that $\mathfrak{a}$ is the coefficient of $\hat{b}^*_{t-1}$. Therefore, we choose the sable root of $\mathcal{P}(\mathfrak{a}) = 0$, i.e., $\mathfrak{a} = \mathfrak{a}_1 \in (-1, 1)$, where

$$\mathfrak{a} = \frac{1}{2}\left\{1 + R^* + \gamma v(1-\alpha_N) - \sqrt{\left[1 + R^* + \gamma v(1-\alpha_N)\right]^2 - 4R^*}\right\}.$$

Note that $\mathfrak{a}$ is real since $\left[1 + R^* + \gamma v(1-\alpha_N)\right]^2 - 4R^* = (R^* - 1)^2 + 2(1 + R^*)\gamma v(1-\alpha_N) + \left[\gamma v(1-\alpha_N)\right]^2 > 0$. The mappings (A.8) also imply the following expressions for $\mathfrak{d}$, and $\mathfrak{e}$, in terms of $\mathfrak{a}$:

$$\mathfrak{d} = -\vartheta(\mathfrak{a} - R^*),$$

and

$$\mathfrak{e} = \left[\frac{1-\rho_{p^*_F}}{1-\rho_{p^*_F} + R^* + \gamma v(1-\alpha_N) - \mathfrak{a}}\right](-\tau\alpha_F) + \left[1 - \frac{1-\rho_{p^*_F}}{1-\rho_{p^*_F} + R^* + \gamma v(1-\alpha_N) - \mathfrak{a}}\right]\left[-\vartheta(\alpha_F - \kappa_F)\right],$$

which together with (28), (A.6), and the definitions $\Phi^{CM}_{p^*_F} = \tau\alpha_F$, and $\Phi^{FA}_{p^*_F} = \vartheta(\alpha_F - \kappa_F)$, can be combined to obtain the analytical expression (31) for $\hat{\pi}^{IM}_t$. Finally, $\omega_{p^*_F} \in [0, 1)$, follows from the facts that $R^* + \gamma v(1-\alpha_N) - \mathfrak{a} > 0$—since $\mathfrak{a} \in (-1, 1)$, $\gamma > 0$, $1 - \alpha_N > 0$, $R^* > 1$ and $\lim_{v \to 0} \omega_{p^*_F} = 0$. ■

A.4. Proof of Corollary 1

Proof. The proof of this corollary follows from our results in Proposition 1, 2 and 3. Points *a)* and *b)* follow from setting $\Phi^{FA}_{p^*_F} = \alpha_F$ and $\Phi^{CM}_{p^*_F} = \alpha_F$, while *c)* follows from *a)* and *b)* combined with the fact that the first-round effects under IM are just a convex combination of these effects under FA and CM. ■

References

Akitoby, B., and T. Stratmann, 2008, "Fiscal Policy and Financial Markets," Economic Journal, Vol. 118(533), pp. 1971-1985.

Anand, R., and E. Prasad, 2010, "Optimal Price Indices for Targeting Inflation Under Incomplete Markets " IMF Working Papers 10/200, International Monetary Fund.

Aoki, K., 2001, "Optimal Monetary Policy Responses to Relative-Price Changes," Journal of Monetary Economics, Vol. 48(1), pp. 55-80.

Azariadis, C., 1993, Intertemporal Macroeconomics, Oxford: Blackwell Publishers.

Backus, D., and G. Smith, 1993, "Consumption and real exchange rates in dynamic economies with non-traded goods," Journal of International Economics, Vol. 35(3-4), pp. 297-316.

Baxter, M., and R., King, 1999, "Measuring Business Cycles: Approximate Band-Pass Filters For Economic Time Series," The Review of Economics and Statistics, Vol. 81(4), pp. 575-593.

Bergin, P., and R., Glick, 2009, "Endogenous Tradability and Some Macroeconomic Implications," Journal of Monetary Economics, Vol. 56(8), pp. 1086-1095.

Bernanke, B., T. Laubach, F. Mishkin, A. Posen, 1999, Inflation Targeting: Lessons from the International Experience, Princeton, Princeton University Press.

Blanchard, O., and J. Gali, 2007, "Real Wage Rigidities and the New Keynesian Model," Journal of Money, Credit, and Banking, Vol. 39(1), pp. 35-66.

Blanchard, O., and C. Kahn, 1980, "The Solution of Linear Difference Models under Rational Expectations," Econometrica, Vol. 48(5), pp. 1305-11.

Bodenstein, M., C. Erceg, and L. Guerrieri, 2008, "Optimal Monetary Policy with Distinct Core and Headline Inflation Rates," Journal of Monetary Economics, Vol. 55, pp. 18-33.

Calvo, G., 1983, "Staggered Prices in a Utility-Maximizing Framework," Journal of Monetary Economics, Vol. 12, pp. 983-998.

Catao, L. and R. Chang, 2010, "World Food Price and Monetary Policy," IMF Working Paper 10/161.

Christiano, L., 2002 "Solving Dynamic Equilibrium Models by a Method of Undetermined Coefficients," Computational Economics, Vol. 20(1), pp. 21-55.

De Paoli, B., 2009a, "Monetary Policy and Welfare in a Small Open Economy," Journal of International Economics, Vol. 77(1), pp. 11-22.

De Paoli, B., 2009b, "Monetary Policy under Alternative Asset Market Structures: The Case of a Small Open Economy," Journal of Money, Credit and Banking, Vol. 41(7), pp. 1301-1330.

Gali, J., and T. Monacelli, 2005, "Monetary Policy and Exchange Rate Volatility in a Small Open Economy," Review of Economic Studies, Vol. 72(3), pp. 707-734.

Gelos, G. and Y. Ustyugova, 2012, "Inflation Responses to Commodity Price Shocks–How and Why Do Countries Differ?" IMF Working Paper 12/225.

Goldberg, J., 2011, "Kwacha Gonna Do? Experimental Evidence about Labor Supply in Rural Malawi" Unpublished Manuscript, University of Maryland.

Gordon, R., 1975, "Alternative Responses of Policy to External Supply Shocks," Brookings Papers on Economic Activity, Vol. 1975(1), pp. 183-206.

International Monetary Fund, 2011, “Managing Global Growth Risks and Commodity Price Shocks—Vulnerabilities and Policy Challenges for Low-Income Countries,”IMF Policy Paper 092111.

Ogaki, M., J., Ostry, and C., Reinhart, 1996, “Saving Behavior in Low- and Middle-Income Countries,” IMF Staff Papers, Vol. 43(1), pp. 38-71.

Schmitt-Grohé, S., and M. Uribe, 2003, “Closing Small Open Economy Models,” Journal of International Economics, Vol. 61, pp. 163-185.

Seale, J., A., Regmi, and J., Bernstein, “International Evidence on Food Consumption Patterns,” USDA Technical Bulletin 1904.

Svensson, L., and S., van Wijnbergen, 1989, “Excess Capacity, Monopolistic Competition, and International Transmission of Monetary Disturbances,” Economic Journal, Vol. 99(397), pp. 785-805.

Woodford, M. 2003, Interest and Prices: Foundations of a Theory of Monetary Policy, Princeton, Princeton University Press.

Woodford, M. 2011, “Simple Analytics of the Government Expenditure Multiplier,” American Economic Journal: Macroeconomics, Vol. 3, pp. 1-35.