FONDAZIONE ENI ENRICO MATTEI

NOTA DI LAVORO

73.2016

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Climate Change: Economic Impacts and Adaptation
Series Editor: Francesco Bosello

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Summary

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Keywords: Coffee, Colombia, El Niño, ENSO, La Niña, Structural VAR

JEL Classification: C32, O13, Q02, Q11, Q54

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1 Introduction

El Niño Southern Oscillation (ENSO) is a naturally occurring phenomenon that changes the global atmospheric circulation and affects sea-level pressure, sea-surface temperatures, precipitation and winds around the globe. Climatologists have made substantial progresses in modeling ENSO and can now predict the arrival of its warm and cold phases, known respectively as El Niño and La Niña, months in advance (see e.g. Barnston et al., 2012).

The socioeconomic impacts of weather fluctuations have been widely investigated (see Dell et al., 2014, for a survey). ENSO events and, more generally, temperature and precipitation anomalies, are associated with lower economic growth rates and agricultural yields (Dell et al., 2012; Hsiang and Meng, 2015; Iizumi et al., 2014; Tack and Ubilava, 2015), commodity price inflation (Brunner, 2002; Cashin et al., 2015; Ubilava, 2016), epidemic diseases (Kovats et al., 2003) and civil conflicts (Hsiang et al., 2011).

We develop a structural econometric model that allows to analyze the Colombian coffee market and to gauge the consequences of ENSO anomalies on the production, exports and real price of Arabica coffee. Colombia is a leading producer of top-quality Arabica coffee and has a shore on the equatorial Pacific, thus its agricultural sector is particularly susceptible to ENSO anomalies.

The first novelty of our work is to isolate the impacts of extreme ENSO events from shocks to economic fundamentals. We identify the effects of ENSO anomalies, while controlling for shocks arising from both the supply and the demand-side of the market. This approach is different from that of other studies on the "ENSO-commodity price inflation" nexus. In fact, existing analyses do not control for supply and demand shocks, that are expected to be the main drivers of the real prices of coffee and of other commodities (Laosuthi and Selover, 2007; Ubilava, 2012, 2016).

The second novelty of our work is to present a Structural Vector Autoregressive (VAR) model for the Colombian coffee market. We posit that the real price of coffee is jointly determined by shocks to the coffee supply, shocks to the demand for Colombian coffee and El Niño (La Niña) anomalies. On the contrary, most studies model and forecast the price of coffee with reduced-form specifications that cannot identify the causes underlying coffee price shocks (see Ghoshray, 2009, 2010; Milas and Otero, 2002; Milas et al., 2004; Otero and Milas, 2001; Vogelvang, 1992).

The third contribution of this study is to the strand of the literature dealing with the macroeconomic effects of coffee price shocks. Some of these studies focus only on price shocks originating from the supply-side, thus neglecting the importance of demand-driven price shocks (Dube and Vargas, 2013; Miller and Urdinola, 2010). In other cases, the cause underlying a given price shock is not explicitly identified (Otero, 2001; Raju and Melo, 2003) and the price of coffee is treated as exogenous (Edwards, 1984, 1986). On the contrary, in our econometric specification the causes underlying price shocks are clearly identified. Since there are no reasons to expect that a coffee price shock, driven by a supply shortfall, might have the same impacts as a price shock driven by exports boom, our model could be used to better understand the linkages between the coffee market and the Colombian economy.

A fourth feature of this study is that we rely on monthly data. On the contrary, most of the previous analyses of the linkages between weather shocks and macroeconomic variables rely on data aggregated at annual or quarterly frequency to match ENSO proxies with measures of aggregate economic activity. This causes the so called "temporal aggregation bias" that is likely to affect both parameter estimates and hypothesis testing. This specification error arises when economic agents make decisions at fixed intervals of time, that are more recurrent than the sampling frequency of the data (Christiano and Eichenbaum, 1987).

We show that during El Niño production and exports increase, while the real price of coffee decreases. On the contrary, the development of La Niña depresses coffee production and exports, while boosting its real price. The overall impact of ENSO shocks is small. In the short-run, ENSO shocks explain 2% of the fluctuations of coffee production and 0.2% of the variability of the real price of coffee. In the long-run, these percentages are 8% and 6%, respectively. Both in the short-run and in the long-run, shocks to the supply coffee are less relevant than demand-side shocks in explaining the real price of coffee.

Our results suggest that a given coffee price shock can have beneficial, detrimental or negligible effects on the Colombian economy, depending on the nature of its underlying cause. Thus, any policy response to coffee price shocks, if any, should be linked to its cause (see Cashin et al., 2015; Edwards, 1984, 1986; Junguito, 1996; Otero, 2001; Raju and Melo, 2003, for a discussion of policy response to coffee price shocks).

The rest of the paper is organized as follows. Section 2 surveys the literature, whereas Sections 3 and 4 provide a background on the ENSO cycle and the Colombian coffee industry. Data and econometric methods are described in Section 5. Results are discussed in Section 6, while Section 7 concludes.

2 Review of the literature

This paper contributes to two strands of the literature: (*i*) studies on the economic impacts of ENSO, and (*ii*) analyses on the dynamics of the coffee market.

(*i*) *Economic impacts of ENSO.* A growing body of literature focuses on the impacts of ENSO on agricultural yields, macroeconomic aggregates and commodity markets, using a variety of econometric techniques, such as: panel data methods (Hsiang and Meng, 2015), reduced-form time series models (Berry and Okulicz-Kozaryn, 2008; Laosuthi and Selover, 2007; Ubilava, 2012, 2016), structural-form time series models (Brunner, 2002; Cashin et al., 2015).

A first set of studies focuses on the economic impacts of ENSO by directly analyzing its linkages with agriculture.Adams et al. (1999) show that while both ENSO extremes lead to economic losses for the U.S. agriculture, La Niña causes greater damages than El Niño. Hsiang and Meng (2015) show that ENSO has a negative and statistically significant effect on cereal production, yield and agriculture value added for a panel of tropical economies (i.e. countries, such as Colombia, whose local temperatures are strongly linked with ENSO). Iizumi et al. (2014) highlight that the response of crop yield to ENSO can be either positive or negative, depending on the geographical location, crop type, and ENSO phases (i.e. El Niño or La Niña).

A second set of studies focuses on the direct effects of ENSO shocks on macroeconomic aggregates, such as GDP growth and inflation. Brunner (2002) demonstrates that El Niño leads to a positive and statistically significant response of commodity price inflation, while the responses of GDP growth and CPI inflation are never statistically distinguishable from zero. Cashin et al. (2015) estimate a Global VAR model for 21 countries and show that

El Niño temporarily boosts inflation in most economies, although its effects on growth vary across countries. The impact of ENSO on local weather and the economic structure of the country jointly determine the sign, the magnitude and the persistence of the response of GDP growth to El Niño. Berry and Okulicz-Kozaryn (2008) show that neither U.S. CPI inflation, nor GDP growth respond to ENSO shocks and fail to discover cyclical co-movements of ENSO and macroeconomic aggregates. Laosuthi and Selover (2007) show that El Niño Granger causes both GDP growth and inflation only in two countries (i.e. South Africa and Australia) out of the 22 countries covered by their study.

A third set of contributions deals with the nexus between ENSO and the price of specific commodities. Although for brevity we focus only on studies dealing with coffee, the interested reader is referred to Ubilava (2016), World Bank (2015) and references therein. Ubilava (2016) implements non-linear time series models to study the impact El Niño and La Niña on the real prices of 46 primary commodities, including coffee. The author shows that the price of Arabica coffee responds symmetrically to El Niño and La Niña shocks. In particular, the response of the price of Arabica coffee to La Niña (El Niño) shocks is positive (negative) and statistically significant for almost a year. Ubilava (2012), relying on a similar methodology, shows that the response to ENSO shocks depends on the variety of coffee and ENSO phases. In general, a shock to ENSO affects coffee prices for up to 12 months, while El Niño (La Niña) decreases (increases) the price of Arabica coffee. On the contrary, Laosuthi and Selover (2007) fail to find evidence of Granger causality between ENSO and the price of coffee.

(*ii*) *Models of the coffee market.* Early attempts of modeling and forecasting coffee production are Gelb (1977), Rourke (1970), and Wickens and Greenfield (1973), who develop economic and econometric models for the world coffee market. A more recent model of the the international coffee market is due to Mehta and Chavas (2008), who analyze the impacts of price interventions on farm, wholesale and retail coffee prices in Brazil.

Numerous studies have focused on modeling and forecasting the prices of different coffee qualities (Ghoshray, 2009, 2010; Milas and Otero, 2002; Milas et al., 2004; Otero and Milas, 2001; Vogelvang, 1992). These contributions implement linear or non-linear reduced-form models to analyze the co-integration between coffee prices.

Given the importance of the coffee industry for the Colombian economy, a strand of the literature has identified feedbacks between shocks to the price of coffee and macroeconomic aggregates, such as money growth, inflation, real GDP, and real exchange rates (see e.g. Edwards, 1984, 1986; Otero, 2001; Raju and Melo, 2003). Differently from our paper, these analyses focus only on exogenous supply shocks (Dube and Vargas, 2013; Miller and Urdinola, 2010), do not distinguish supply-side from demand-side coffee price shocks (Otero, 2001; Raju and Melo, 2003) and consider the price of coffee as exogenous with respect to Colombian macroeconomic variables (Edwards, 1984, 1986).

3 El Niño Southern Oscillation and its measurement

El Niño Southern Oscillation is the effect of the interaction between atmosphere and ocean in the tropical Pacific region, which influences climate patterns worldwide. ENSO is a single natural climate phenomenon with three distinct phases: El Niño, La Niña and a neutral state, where the atmosphere and ocean conditions are close to their long-term average.[1]

The climate in the tropics acts as a "coupled system": as the ocean surface temperature changes, so does air pressure in the region, and vice-versa. "El Niño" refers to the ocean component of ENSO (i.e. the cycling of sea-surface temperatures between below- and above-normal), while the "Southern Oscillation" (SO) captures large-scale fluctuations in air pressure, i.e. the atmospheric component of ENSO.

El Niño, the Spanish expression for "the Boy Child", is the name that South American fishermen have given to the phenomenon of warmer-than-normal ocean water temperatures observed during the Christmas season. El Niño is the warm phase of the ENSO cycle, characterized by higher-than-usual sea temperatures in the central and eastern equatorial Pacific Ocean. It is also the negative phase of the SO, when abnormally high air pressure covers Indonesia and abnormally low air pressure characterizes the east-central tropical Pacific. During El Niño years, trade winds, which in the neutral phase blow from east to west along

[1] For more details see World Meteorological Organization (2014) and the ENSO Resources web-page of the International Research Institute for Climate and Society available online at http://iri.columbia.edu.

the equator, weaken or even reverse their direction. Usually, El Niño starts in spring and peaks from November to January.

El Niño is often, but not always, followed by La Niña, which is characterized by cooler-than-usual sea water in the equatorial Pacific Ocean. La Niña is the cold phase of ENSO and the positive phase of the SO, when abnormally low air pressure covers Indonesia and abnormally high air pressure covers the east-central tropical Pacific. La Niña develops during spring and peaks between November and February.

El Niño and La Niña events typically last about a year, but it is not uncommon for La Niña to last for two years or more. El Niño occurs irregularly, approximately every 2-7 years.

Since during El Niño and La Niña both ocean temperatures and air pressure are away from their long-term average values, the two most commonly used ENSO indicators track sea surface temperature and air pressure anomalies.

The first indicator of ENSO, which is used in Sections 5 and 6 of this paper, is based on sea surface temperature (SST) anomalies. The U.S. National Oceanic and Atmospheric Administration defines El Niño and La Niña as episodes with five consecutive three-month running mean of SST anomalies in the so-called "Niño 3.4 region" above (below) the threshold of +0.5°C (-0.5°C).[2] The second indicator is the Southern Oscillation Index (SOI). It is calculated using the pressure differential between Tahiti (east-central tropical Pacific) and Darwin, Australia (south of Indonesia). The SOI is below zero during El Niño episodes (i.e. the negative phase of the SO) and above zero during La Niña years (i.e. the positive phase of the SO).[3]

4 The Colombian coffee industry

Past El Niño and La Niña episodes have had severe impacts on the economy of Colombia, since it heavily depends on energy and agricultural commodity exports. Poveda et al. (2001)

[2]The SST index is also known as the Oceanic Niño Index. The "Niño 3.4 region" is bounded by 120°W-170°W and 5°S-5°N.

[3]Over the period 1990-2015 the sample correlation between SST and SOI is -0.73. A map of the "Niño 3.4 region" and a plot of the two indicators are reported in the Appendix

report that the drought following the 1997-98 El Niño caused a 10% loss in coffee production. Moreover, because of the negative impact on many agricultural commodities, Colombia was forced to import more than 3.5 million tons of grains and other food supplies. Hoyos et al. (2013) state that, due to flooding, destruction of infrastructures and payment of government subsidies, the La Niña episode of 2010-11 caused losses for more than US $7.8 billion.

Colombia is the most renowned producer of high-quality coffee.[4] Although in recent years the importance of the coffee industry for the Colombian economy has decreased, it remains an important source of employment and a force contributing to stability and prosperity of the rural areas of the country (Dube and Vargas, 2013; Colombian Coffee Growers Federation, 2013; Miller and Urdinola, 2010).[5]

During the 2014-15 marketing year, Brazil, Vietnam and Colombia accounted respectively for 35.4%, 17.9%, 8.7% of world coffee production. While Brazil and Vietnam produce both Robusta and Arabica coffee, Colombia only supplies high-quality Arabica varieties. In terms of Arabica production, Colombia is second only to Brazil.[6] However, Brazilian varieties, produced on a massive scale at low altitudes and harvested mechanically, are perceived to be of lower in quality than Colombian coffee, which is harvested by hand at higher altitudes on the foothills of the Andes in the "Coffee Triangle" of Caldas, Quindío and Risaralda (Andrade et al., 2013).

Several factors, such as climatic conditions and weather patterns, physical and chemical characteristics of the soil, latitude and altitude of the growing zones, the botanical origin of the varieties produced and the low degree of mechanization, contribute to the perceived high-quality of Colombian coffee and explain its price premium over other coffee varieties, such as Robusta.

[4]Source: U.S. National Coffee Association, 2014 National Coffee Drinking Trends Report.

[5]In 2014 Colombia's top exports were: crude petroleum (45%), coal briquettes (13%), refined petroleum products (4.9%) and coffee (4.7%). In 1990 Colombia exported mainly crude petroleum (24%), coffee (23%) and bananas (6.8%). In 1980 coffee represented 59% of total exports. Source: The Economic Complexity Observatory.

[6]Robusta represents 96% (31%) of total production in Vietnam (Brazil), although yields beans of inferior quality than Arabica (Ghoshray, 2010). Focusing only on Arabica, the three largest producers in 2014-15 were Brazil (43.1%), Colombia (15.4%) and Ethiopia (7.5%). Source: U.S. Department of Agriculture.

More specifically, Arabica coffee can be further divided into Colombian Milds, Brazilian Naturals, and Other Milds. Since Colombian Milds are considered to be of the highest quality, they are sold at a premium over the price of the other types of coffee. During the 1990-2015 period, the average prices of Colombian Milds, Other Milds, Brazilian Naturals and Robusta coffee were, respectively, 135.0, 127.2, 112.4 and 72.4 U.S. cents per pound (Source: ICO Composite & Group Indicator Prices).

The growing trend in the consumers' willingness to pay for certified products is generally acknowlwdged in the literature (see e.g. Arnot et al., 2006; Nielsen, 2015). On this respect, an additional peculiarity of Colombian market is that, according to the Sustainable Coffee Program (2014), in Colombia certified coffee accounts for 14% of total coffee exports, a higher percentage than in Brazil (12%) and Vietnam (9%).

5 Data & Methods

5.1 Data

We estimate a Structural VAR model with four variables, namely $\mathbf{y}_t \equiv [sst_t, \Delta prod_t, cexp_t, rpc_t]'$, where sst_t denotes Sea Surface Temperature (SST) anomalies in the "Niño 3.4 region", $\Delta prod_t$ is the percent growth rate of coffee production in Colombia, $cexp_t$ represents the logarithm of Colombian coffee exports and rpc_t is the external price of Colombian coffee in real terms.[7]

All variables are sampled monthly and cover the period January 1990 - May 2016, for a total of 317 observations. Although data are available starting from the late 1950's, the estimation sample begins in January 1990, since, before that date, the price of coffee was

[7]Production and exports - in thousands of bags of 60 kg green bean equivalent - as well as the export price of Colombian coffee - in US cents per pound - are provided by the Colombian Coffee Growers Federation. The price of coffee has been converted from nominal to real terms using CPI data sourced from the Federal Reserve Bank of St. Louis (mnemonic: CPIAUCSL). Variables $cexp_t$ and rpc_t are expressed in percent deviations from their sample averages. ENSO indicators (i.e. SST anomalies and SOI) are provided by the National Oceanic and Atmospheric Administration.

regulated under the International Coffee Agreement (ICA) regime.[8]

[Figure 1 here]

Figure 1 shows that the real price of coffee is highly volatile. This empirical aspect is coherent with a low price elasticity of supply, and low price and income elasticities of demand, whose interaction tends to magnify the price impact of actual and expected supply shortages (Mehta and Chavas, 2008; Ponte, 2002).

5.2 Identification of the Structural VAR model

Our structural VAR model is recursively identified and can be written as:

$$\mathbf{A}_0\mathbf{y}_t = \boldsymbol{\mu}_t + \sum_{j=1}^{24} \mathbf{A}_j\mathbf{y}_{t-j} + \boldsymbol{\varepsilon}_t \tag{1}$$

where $\mathbf{y}_t \equiv [sst_t, \Delta prod_t, cexp_t, rpc_t]'$, $\boldsymbol{\mu}_t$ is a vector including a constant and seasonal dummy variables and $\boldsymbol{\varepsilon}_t$ is a vector of serially and mutually uncorrelated structural innovations. We choose a VAR model that includes 24 lags of each variable, since coffee production involves long delays between planting, cropping, harvesting and marketing (e.g. it takes at least two years before new coffee trees begin to bear fruits; see Ponte, 2002). Moreover, Arabica coffee trees are characterized by a "biennial bearing cycle": a high-production year alternates with a low-production year (Rourke, 1970; Wickens and Greenfield, 1973). Reduced-form VAR error terms, $\boldsymbol{e}_t$, are given by $\boldsymbol{e}_t = \boldsymbol{A}_0^{-1}\boldsymbol{\varepsilon}_t$ and are estimated with Ordinary Least Squares on the reduced-form of model (1) (Kilian and Lütkepohl, 2016). Model identification, which builds on Kilian (2009), is achieved by imposing the following set of

[8] The first International Coffee Agreement (ICA) was signed in 1962 by most consuming and producing countries with the aim of stabilizing the price of coffee. Under the ICA regime a target price (or price band) was set and export quotas allocated to each coffee producer. The ICA failed to be renewed in July 1989 (Ponte, 2002).

exclusion restrictions on $\boldsymbol{A}_0^{-1}$:

$$\begin{pmatrix} e_t^{sst} \\ e_t^{\Delta prod} \\ e_t^{cexp} \\ e_t^{rpc} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{ENSO shock}} \\ \varepsilon_t^{\text{coffee supply shock}} \\ \varepsilon_t^{\text{external demand shock}} \\ \varepsilon_t^{\text{residual shock}} \end{pmatrix} \tag{2}$$

The presence of zeroes (i.e. exclusion restrictions) in system (2) can be motivated as follows.

An "ENSO shock" is defined as an unpredictable change of the SST index. Positive ENSO shocks identify unpredictable El Niño events, while unpredictable negative changes of the SST index represent La Niña episodes. Consistently with the identification approaches of Brunner (2002) and Cashin et al. (2015), our identification scheme implies that an ENSO shock affects Colombian coffee production, exports and real price within the same month, but not vice-versa. Without further restrictions, this means that ENSO shocks can move the supply, as well as the demand schedule. In line with the empirical evidence in Ubilava (2012, 2016), our model implicitly assumes that the responses of coffee price, production and exports to positive and negative ENSO shocks are symmetric (i.e. the responses change sign, but are of the same magnitude). Moreover, our model also implies that the timing of the responses to negative and positive ENSO shocks is the same.

Innovations to Colombian production not explained by ENSO shocks are referred to as "coffee supply shocks". The supply of coffee is assumed not to respond on impact to external demand shocks. On the contrary, a supply shortage due to ENSO-related weather events, or to the spread of plant diseases, leads to an immediate change in coffee production. This is in line with theoretical models for the coffee market which assume a vertical coeffe supply (Wickens and Greenfield, 1973; Mehta and Chavas, 2008; Rourke, 1970). Low empirical estimates of short-run supply elasticity can be reconciled with the fact that it takes years before new trees start bearing coffee beans and reach full productivity (Ghoshray, 2010; Ponte, 2002).

Innovations to Colombian coffee exports that cannot be explained based on ENSO or supply shocks are called “external demand shocks”. These shocks are specific to the external demand for Colombian coffee and do not include shocks to the domestic demand for coffee.

Lastly, innovations to the real price of coffee not explained by El Niño, supply, or external demand shocks are “residual shocks”. They can capture, at least in principle, a variety of shocks hitting the real price of coffee, such as: shocks to internal coffee demand, shocks to the supply of coffee in other major producing countries (such as Brazil and Vietnam), preferences shocks, and unexpected fluctuations in the precautionary demand for coffee, driven by uncertainty about future coffee supply shortages. Increases in the real price of coffee due to the “residual shocks” affect coffee exports with a delay of at least one month. In Section 6 we discuss three episodes of shocks to the real price of coffee which justify the interpretation of “residual shocks” as innovations to precautionary demand for coffee.

6 Empirical Results

6.1 The evolution of structural shocks

Figure 2 shows the dynamics the four structural shocks that drive the real price of Colombian coffee displayed in Figure 1.

[Figure 2 here]

Panel (a) reveals that ENSO shocks exhibit several positive and negative spikes in correspondence of El Niño and La Niña events. For example, both in 1997 and in 2015, a large positive ENSO shock is immediately followed by a negative ENSO surprise. This is consistent with the fact that these two years were characterized by a very strong El Niño, which anticipated the development of La Niña.

A joint inspection of panels (a) and (b) shows that La Niña of 2007-08 has been one of the main factors contributing to the outbreak of the “coffee rust” (Avelino et al., 2015). This plant disease led to the negative supply shock observed in 2008, when Colombian production dropped by 31% compared to the level of 2007 (see panel (b)).

Shocks to the real price of coffee not attributable to ENSO, supply or external demand innovations are depicted in panel (d). The dynamics of this series might, in principle, be ascribed to a host of factors, such as supply shortages in other exporting countries, shocks to the domestic, as well as to the precautionary demand for Colombian coffee, and shocks to consumers' preferences. We now discuss the first historical episode which motivates our interpretation of "residual shocks" as innovations to precautionary demand for coffee.

The Brazilian frost of 1994. Between January and September 1994 period the price of coffee almost tripled. Figure 2 shows that in this year only "residual shocks" exhibited a positive spike, which almost entirely explains the corresponding jump int real price of coffee.

Shocks to consumers' preferences can be excluded from the list of explanations because changes in tastes typically evolve gradually. An example is the change in U.S. consumers' drinking habits, moving away from soluble coffee (mainly produced with Arabica) towards ground coffee (mainly produced with Robusta).[9] Hence, we would expect to see a series of shocks of the same sign and not a single spike. For the same reasons, the 1994 episode cannot be attributed to the slow growing trend in coffee consumption in emerging markets, such as China and India (Lewin et al., 2004).

Given that during the 1990-2015 period domestic consumption accounted only for 9.8% of Colombian coffee production (USDA - Production, Supply and Distribution Database), and that in 1994 it did not increase significantly, it is hard to believe that a price jump could have been driven by unexpected changes in Colombia's internal demand for coffee.

Moreover, there is no evidence of a significant production shortfall in other coffee producing countries. On the contrary, between 1993 and 1994, production in Brazil, Vietnam and at the world level increased by 0.1%, 18.4%, 2.9%, respectively (source: ICO). Therefore, the interpretation of the residual shocks category as supply shocks in other producing countries is not consisted with the historical account of the coffee market in 1994.

We are left with the possibility of interpreting the "residual shocks" as a shocks to the

[9]This new consumption pattern started in the 1980's and is associated with the growing importance of certified single origin coffees, an increase of out-of-home consumption and with the proliferation of coffee chains and specialty shops (Ponte, 2002).

precautionary demand for coffee. On this respect, it is important to remember that two frosts affected Brazil in June and July 1994. Since by June most of the coffee-growing areas had already been harvested, effects on Brazilian production were visible only in 1995, which recorded a 36% drop in production with respect to the 1994 levels. Notwithstanding the delayed effect of frosts on production, the 1994 spike in the residual shock series is consistent with the notion of a price-boosting positive shock to precautionary demand, caused by uncertainty about the future availability of coffee production. Market analysts highlight that coffee futures prices rose immediately after each of the two frosts, reflecting the fact that investors were reacting on the basis of changes in their expectations.[10]

6.2 Historical decomposition of the real price of coffee

Figure 3 illustrates the cumulative impact of each structural shock to the real price of Colombian coffee.

[Figure 3 here]

The first three graphs show that demand, supply shocks, and - to a certain extent - ENSO shocks typically cause long-lived price movements. On the contrary, we can see that shocks to the precautionary demand for coffee contribute to the price of coffee with more short-lived abrupt movements. This reinforces our interpretation that these structural shocks capture changes in expectations about the future prospects of supply relative to demand, which are immediately priced (see Kilian, 2009, p. 1054).

We now focus on two additional episodes which show that our interpretation is consistent with the historical developments of the real price of Colombian coffee.

[10]The New York Times (1994) reports that: *"Coffee futures prices rose to an eight-year high yesterday after a second frost in coffee-growing areas of Brazil"* (...) *"some analysts said that at least half of Brazil's 1995-96 crop might have been destroyed in the two frosts."* Torday (1994) writes "*Analysts said the surge in prices reflected fears that further attacks could occur because the winter can last until August*"; moreover he states that "*The disaster struck at a time when coffee-producing countries had only light supplies of beans because of several years of fierce competition for market share, and also because of an agreement to limit production in an effort to bid up prices.*."

The Brazilian drought of 2014. Between January and March 2014 the real price of Colombian coffee increased by 66%, moving from \$1.3 to \$2.2 per pound.

Panel (a) of Figure 3 shows that, consistently with the fact that in 2014 ENSO was in a neutral phase and that there were optimal climatic conditions in coffee-growing regions, the contribution of the first structural shock to the real price of coffee is negative, but very close to zero.

Moreover, panel (b) and (c) Figure 3 highlight that neither supply, nor external demand shocks have had any significant impact on the price increase of 2014. Supply shocks accounted only for a very small fraction of the price increase. In fact, in 2014 production was growing less than during the 2010-2013 period, when a restoration program involving the re-plantation of 40% of coffee trees started with the aim of recovering from the damages of coffee rust disease.

We can also exclude that the contribution of this shock to the price increase could be ascribed to an actual drop in production in other major producing countries. For instance, it is unlikely that the 7% reduction in Brazilian production between 2013 and 2014, might have been responsible for the entire price increase. To put this number in perspective, we notice that year-on-year variations associated with the natural biennial bearing cycle that characterizes Brazilian coffee production are in the range -20% to -15%.

The main cause underlying the price hike of 2014 is thus a positive shock to the precautionary demand for coffee, which reflects expectations of a production shortfall. In early 2014 Brazilian coffee producing regions were hit by extremely hot and dry weather. The fears that the heat and lack of rain could affect coffee beans and lead to a supply shortage in 2015 are captured by an increase in precautionary demand at the beginning of 2014.[11]

"La roya del café": 2008-11. An orange-colored fungus known as "la roya", the Spanish word for "rust", ravaged coffee plantations in Colombia, Central America, Mexico, Peru and Ecuador between 2008 and 2011. As a consequence, Colombian production plunged by 38%

[11] Focusing on futures prices, Terazono (2014) states that: "*Coffee prices jumped (...) as continued worries about hot and dry weather spurred buying by hedge funds and other financial investors.*" Derby (2014) confirms that "*Coffee prices jumped (...) as worries about poor weather conditions in Brazil, the worlds biggest grower and exporter of coffee, triggered active buying.*"

between 2007 and 2012. During this period the real price of coffee was on a growing trend and increased by 96%, moving from 1.3$ per pound in January 2008 to 2.4$ per pound in December 2011.

Our model shows that two forces contributed to the real price of coffee during this period (see Figure 3). Since 2008, a series of positive shocks to precautionary demand for coffee has put upward pressure on the real price. The price-boosting impact of these shocks has somehow been limited by a series of positive supply shocks that are visible only from 2010.

Shocks in the bottom panel of Figure 3 capture expectations of supply shortages driven by the outbreak of "la roya", as well as those associated with other events that created uncertainty about the availability of future coffee production relative to expected consumption (The Guardian, 2011).[12]

It is worth pointing out that during and before the 2008-11 period two La Niña episodes have affected Colombia, one in 2007-08 and another in 2010-11. By decreasing temperatures and sunlight and increasing rainfalls and soil moisture, not only does La Niña raise the hazard of the development of "la roya", but also it magnifies the severity of its effects (Avelino et al., 2015; Poveda et al., 2001).

6.3 Impulse response analysis

Figures 4 and 5 present the response of the Colombian production, exports and real price of coffee to a one-standard deviation shock to ENSO, supply, external and precautionary demand for coffee. Each panel shows the estimated impulse response function (IRF), as well as one and two-standard error bands (namely, 68% and 95% confidence intervals), based on a recursive-design wild bootstrap with 2000 replications (see Gonçalves and Kilian, 2004).

The impacts of El Niño on the coffee market. In Figure 4 we focus on the IRF generated by a positive ENSO shock, which, as an unpredictable positive change in SST anomalies, signals the outbreak of El Niño conditions.

[12] A case in point is 2011 frost in Brazil. According to Almeida and Roy (2011): "*The chance of frost in Brazil increased with the weakening of La Niña. (...). Should cold weather damage trees this year, coffee may rise to a record $4.20 a pound, the median in a Bloomberg survey of 11 analysts, traders and investors.*"

[Figure 4 here]

In the coffee-growing zones of Colombia, El Niño tends to increase temperatures and sunlight and to decrease rainfalls and soil moisture (Poveda et al., 2001). These factors stimulate the growth and flowering of coffee trees and hence have a positive impact on production (Café de Colombia, 2014).

Figure 4 confirms that a positive ENSO shock has beneficial impacts on production and exports. The outbreak of El Niño yields a temporary, although long-lived increase in coffee production and exports. The IRF of production becomes durably significant at the 95% confidence level with a delay of at least 12 months. It then remains statistically significant, at the 68% confidence level, up to 21 months after the positive ENSO shock.

The response of exports to ENSO shocks is further delayed. The IRF becomes durably significant at the 95% confidence level only after 16 months, but 5 months later it is no more statistically distinguishable from zero. The behavior of these responses is explained by the fact that any impact of ENSO on production and exports must incorporate the delays characterizing coffee production cycle. The result that a positive ENSO surprise leads to an increase in coffee exports might be rationalized by the geographical variability of its effects (see e.g Iizumi et al., 2014 and Cashin et al., 2015). Therefore, the rise in Colombian exports might serve to compensate an El Niño-driven production shortfall in another country (Ubilava, 2012).

The bottom panel of Figure 4 displays the response of the real price of coffee to a positive ENSO surprise. On average, over the 1990-2016 period, the development of El Niño has led to a reduction of the real price of Colombian coffee that lasts up to 16 months after the shock. However, the IRF of the real price is negative and statistically significant only using the 68% confidence bands and in the first semester following the ENSO surprise.

The price-depressing effects of El Niño can be reconciled with the fact that El Niño has two positive impacts, one on production, the second on exports. In the presence of a vertical supply, which of the two effects prevails will depend on the price elasticity of demand. In the case of coffee, the short-run price elasticity of both demand and supply is low (Mehta and Chavas, 2008; Ponte, 2002), therefore the price decrease due to the "supply effect" might dominate the price increase due to the "external-demand effect".

Our model implies that to gauge the effects of a negative ENSO surprise (i.e. La Niña) the IRFs of production, exports, and the real price of coffee should be simply translated on the horizontal axis. Hence, following the outbreak of La Niña, coffee production and exports decrease, while the real price of coffee increases.

During La Niña temperatures and sunlight decrease and rainfalls and soil moisture increase (Poveda et al., 2001). The complex interaction of these conditions lower the productivity of coffee plantations and boosts the hazard of plant diseases and floods. Notwithstanding different geographical impacts of ENSO, La Niña increases the severity and the probability of diseases, such as the coffee rust (Avelino et al., 2015). Thus, at least in principle, La Niña can be more harmful than El Niño, whose effects are generally beneficial for coffee production (Café de Colombia, 2014). Overall, these results are in line with those of Ubilava (2012, 2016), who focuses on the nominal price of coffee and implements non-linear reduced form models.

Impulse-responses for the coffee market. We now concentrate on the coffee market block of the Structural VAR (i.e the last three equations of system (2)). All shocks presented in Figure 5 are expected to generate an increase in the real price of coffee. Therefore, we focus on a negative supply shock, which represents an unpredictable decrease of Colombia's coffee production, and positive shocks to external and precautionary demand for Arabica coffee.

[Figure 5 here]

A negative supply shock causes an abrupt decline in Colombian coffee production on impact, immediately followed by a rebound. The drop is permanent and the IRF remains negative and statistically significant at the 68% confidence level for almost two years. This shock also causes a fall in exports, which is long-lived and statistically significant, at the 95% confidence level. Moreover, an unexpected supply disruption generates a permanent real price increase, that is statistically significant at the 68% confidence level.

The response of production to a positive shock to the external demand for Colombian coffee is never statistically distinguishable from zero. This is due to the fact that coffee production cannot be modified in the short-run. An unexpected boom in the external demand for coffee causes an immediate increase in exports, followed by a partial reversal. The IRF ceases to be statistically significant, at the 95% confidence level, a quarter after the shock. This shock also generates a permanent real price increase, that is statistically significant at the 68% confidence level for over a year.

An unanticipated rise in the precautionary demand for coffee has no impact on production and exports, but causes a permanent real price increase. There is evidence of overshooting in the response of the real price. The IRF peaks after a quarter, then it gradually declines, but remains statistically significant at the 95% confidence level. Notice that this behavior is rather different from the dynamics of the IRF of price to supply shocks. In that case, there is no overshooting. Since the IRF builds up gradually and peaks 15 months after the shock. A similar pattern is thus expected also in the case of a foreign supply shock. All in all, the presence of overshooting reinforces our interpretation of the last structural innovations as shocks to expectations driven by fears over the availability of future coffee supply. These shocks are transmitted almost immediately to the price of coffee, while supply and external demand shocks take more time to be propagated.

6.4 Forecast error variance decomposition

Table 1 shows the percentage contributions of ENSO, supply and demand shocks to the overall variability of Colombian coffee production, export and real price, based on the forecast error variance decomposition of our Structural VAR model.

[Table 1 here]

Over the 1990-2016, period the explanatory power of ENSO shocks for the Colombian coffee market is, on average, small. On impact, they account only for a tiny percentage of the variation in coffee production (2.2%), exports (0.02%) and real price (0.2%). In the long-run, the explanatory power of ENSO shocks for production and price rises to 8% and 6%, respectively.[13]

[13]Ubilava (2016) shows that, on impact (after two years), ENSO shocks can explain 13% (17%) of the

Focusing on panel (c) of Table 1, precautionary demand shocks explain, on impact, 94% of the variation in the real price of coffee, followed by supply shocks (3%) and external demand shocks (2%). In the long-run, both external demand and supply shocks gain importance and explain 14% and 11% of the variation of the real price of coffee. The explanatory power of precautionary demand shocks decreases to 69%.

To sum up, in the long-run the price of coffee is mainly explained by shocks to the demand-side, which account for 83% of its variation. The limited explanatory power of ENSO for production, coupled with the fact that demand-side disturbances seem more important than supply-side shocks, help explaining why there is only a mild response of the real price of coffee to ENSO anomalies.

6.5 Robustness checks

Our results are robust to several modifications of the reference model (1)-(2) presented in Section 5.

A different ENSO indicator. In Sections 6.1-6.4 we have used SST anomalies to determine whether ENSO was in its cold (La Niña) or warm phase (El Niño). An alternative ENSO indicator is the Southern Oscillation Index (SOI). The SOI is negative during El Niño episodes, while it is positive when La Niña conditions prevails in the tropical Pacific Ocean.

We consider a Structural VAR of order 24 for $\mathbf{y}_t \equiv [-soi_t, \Delta prod_t, cexp_t, rpc_t]'$. Notice that in order to identify positive ENSO shocks as El Niño episodes, we have included the negative of SOI in the model. A comparison of Figure 6 with Figure 4 shows that using SOI in place of SST yields qualitatively similar results.

[Figure 6 here]

VAR lag-order. Results in Sections 6.1-6.4 are based on the estimation of a VAR model that includes 24 lagged values of each endogenous variable. Since Arabica coffee trees feature a

variation of the price of Arabica coffee varieties. The lower explanatory power of ENSO shocks reported in our study (i.e. 0.2% on impact and 8% after two years) can be attributed to the fact that we have explicitly modeled both supply and demand shocks.

"biennial bearing cycle", such a high lag-order is necessary to capture the linkages between the cyclical fluctuations of prices and production, as well as seasonal effects.

Figure 7 shows the IRFs of coffee production, exports and prices arising from VAR models of order 6 and 12. In both cases the resulting IRFs are qualitatively equivalent to those reported in Figure 4. However, the IRFs arising from lower-order VAR models are more precisely estimated. It is well known that the choice of the VAR lag-order is subject to a trade-off: too many lags lead to less precise IRF estimates, while, if the lag order is too low, misleading estimates and inference can occur (Kilian, 2001).

[Figure 7 here]

Strong exogeneity of SST. All the results presented so far rely on the assumption that ENSO proxies are pre-determined with respect to the Colombian coffee market. An alternative, and possibly more realistic, working hypothesis is to assume that ENSO proxies are strongly exogenous. Operationally, the strong exogeneity assumption imposes a set of zero restrictions on the coefficients of lagged production, export and real price of coffee in the reduced-form VAR equation for sst_t. Hence, the restricted VAR model has been estimated with Iterated Feasible Generalized Least Squares and the resulting IRFs of coffee production, exports and prices to a positive ENSO shock are presented in Figure 8. Since the restricted VAR is characterized by a smaller number of estimated parameters, the IRFs should be more precisely estimated. Nevertheless, the restricted IRFs are qualitatively identical to those reported in Figure 4.

[Figure 8 here]

Exogenous variables. In our model of the Colombian coffee market the price of coffee is jointly determined by four structural shocks, namely ENSO surprises, shocks to the supply, shocks to the external and to the precautionary demand for coffee. As illustrated in Section 6.1, a possible alternative interpretation is that the last category of structural innovations reflect shocks to the supply in other coffee-producing countries, such as Brazil.

To check the validity of this alternative explanation, we compute the IRFs from model (1)-(2) augmented by the real price of Brazilian coffee, as well as the IRFs obtained by adding to model (1)-(2) the average real coffee price of Other Milds, Brazilian Naturals and Robusta (see Figure 9). Both prices are assumed to be exogenous. To avoid potential endogeneity problems, we include the lagged values of those prices in the VAR model. Data have been sourced from the ICO website.

Overall, Figure 9 shows that there are not significant differences between the two sets of IRFs with exogenous variables and the IRFs based on the original VAR model (1)-(2). Therefore, we conclude that our model is a reasonable representation of the Colombian coffee market. In particular, these findings suggest that actual and expected production shortfall in other coffee producing countries are transmitted to the real price of Colombian coffee as shocks to the precautionary demand.

[Figure 9 here]

7 Conclusions and discussion

The impacts of El Niño and La Niña on rainfalls, temperatures and tropical cyclone activity vary substantially between world regions and seasons of the year and are not limited to the countries with shores on tropical Pacific, but affect normal weather conditions in many parts of the world (see e.g. Davey et al., 2014; World Meteorological Organization, 2014). During El Niño and La Niña years the occurrence of floods, droughts, tornadoes, hail storms and other climate-related disasters becomes more predictable (Allen et al., 2015; Goddard and Dilley, 2005; World Meteorological Organization, 2014). Incorporating these predictions into early warning systems can save lives, reduce economic losses and boost the benefits of ENSO where it has positive economic effects (Adams et al., 1999; Bouma et al., 1997; Changnon, 1999; Costello et al., 1998; Iizumi et al., 2014; Sun et al., 2006; Tack and Ubilava, 2015).

Since climatologists can predict ENSO anomalies up to two years in advance (Chen et al., 2004), these forecasts can be used by to optimize the response of policy authorities and coffee industry stakeholders to El Niño and La Niña anomalies. However, optimization of the policy responses to extreme weather events requires not only a "good climatological model" that allows to forecasts the arrival of El Niño and La Niña, but also a deep understanding of the propagation mechanisms through which unpredictable ENSO shocks influence the economic variables of interest.

Our structural econometric model is a first step in this direction, in fact it allows to better understand the causes of different shocks to the price of coffee in Colombia. Therefore, we can measure the impacts ENSO shocks on the Colombian coffee industry, while controlling for shocks arising from both the supply and the demand-side of the market, which are also crucial in driving the price of coffee. We show that the overall impact of ENSO shocks on the price of coffee is small and that, both in the short-run and in the long-run, demand-side shocks have more explanatory power than supply-side shocks.

A second distinguishing characteristic of our study is to provide an in-depth analysis for a single country and a specific commodity. Focusing on Colombia, rather than looking directly at the world coffee market and hence at global price indicators, such as those made available by the International Coffee Organization (ICO) or futures prices, facilitates identifying the economic effects of ENSO. In fact, since the linkages between global and domestic prices are often weak, the transmission of any production shortfall caused by ENSO anomalies from the local to the world price of a commodity might involve long delays (World Bank, 2015).

Moreover, focusing on a single country is preferable because the weather effects of El Niño and La Niña are highly heterogeneous across countries and world regions and so is the response of commodity prices to ENSO anomalies (Cashin et al., 2015; Iizumi et al., 2014). A case in point is coffee. El Niño tends to create favorable conditions for the production of Arabica varieties, mainly grown in South America, while it often leads to decrease the production of Robusta, mainly grown in Southeast Asia (Ubilava, 2012, 2016). If the analysis of the coffee market is confined to the world level, production shortfalls for Robusta coffee can be offset by the beneficial impacts of El Niño on Arabica production. Therefore, looking at the coffee price from a global perspective without allowing for spillover effects, rather than analyzing each country separately, would lead to information losses and potential underestimation of the effects of ENSO shocks.

Acknowledgments

We thank seminar participants at the Euro-Mediterranean Center on Climate Change, Bologna, the University of Milan, the University of Milan-Bicocca and the Fondazione Eni Enrico Mattei, Milan, Italy. The first author gratefully acknowledges financial support from the Italian Ministry of Education, University and Research [MIUR, PRIN 2010-2011, n. 2010S2LHSE-001] and from the Euro-Mediterranean Center on Climate Change, Bologna, Italy.

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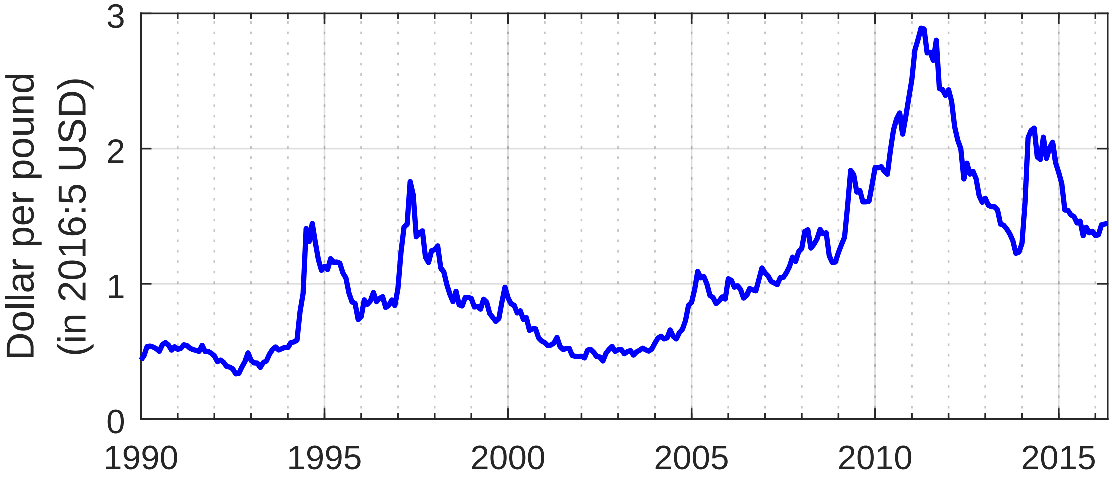
Tables & Figures

Table 1: Percent contribution of each shock to the variability of coffee production, exports and real price

Panel (a) Variance decomposition of coffee production ($\Delta prod_t$)				
Horizon	ENSO shock	Supply shock	Demand shock	Precautionary Demand shock
1	2.18	97.82	0.00	0.00
3	2.86	95.47	0.75	0.91
12	6.83	82.67	4.47	6.03
24	7.68	72.77	8.48	11.07
∞	8.29	69.48	10.98	11.25
Panel (b) Variance decomposition of coffee exports ($cexp_t$)				
Horizon	ENSO shock	Supply shock	Demand shock	Precautionary Demand shock
1	0.02	10.1	89.89	0.00
3	0.22	17.74	81.57	0.47
12	5.08	35.25	54.63	5.04
24	13.22	35.36	45.49	5.92
∞	12.83	33.91	42.51	10.75
Panel (c) Variance decomposition of the real price of coffee (rpc_t)				
Horizon	ENSO shock	Supply shock	Demand shock	Precautionary Demand shock
1	0.24	2.75	2.09	94.92
3	0.82	2.91	4.88	91.39
12	1.72	6.98	6.66	84.63
24	1.71	13.69	5.58	79.01
∞	5.80	11.52	13.74	68.94

Notes: Forecast error variance decomposition (FEVD) for the growth rate of coffee production, $\Delta prod_t$, coffee exports, $cexp_t$, and the real price of coffee, rpc_t, based on the structural VAR model. FEVD at horizon "∞" is approximated by FEVD at horizon 600.

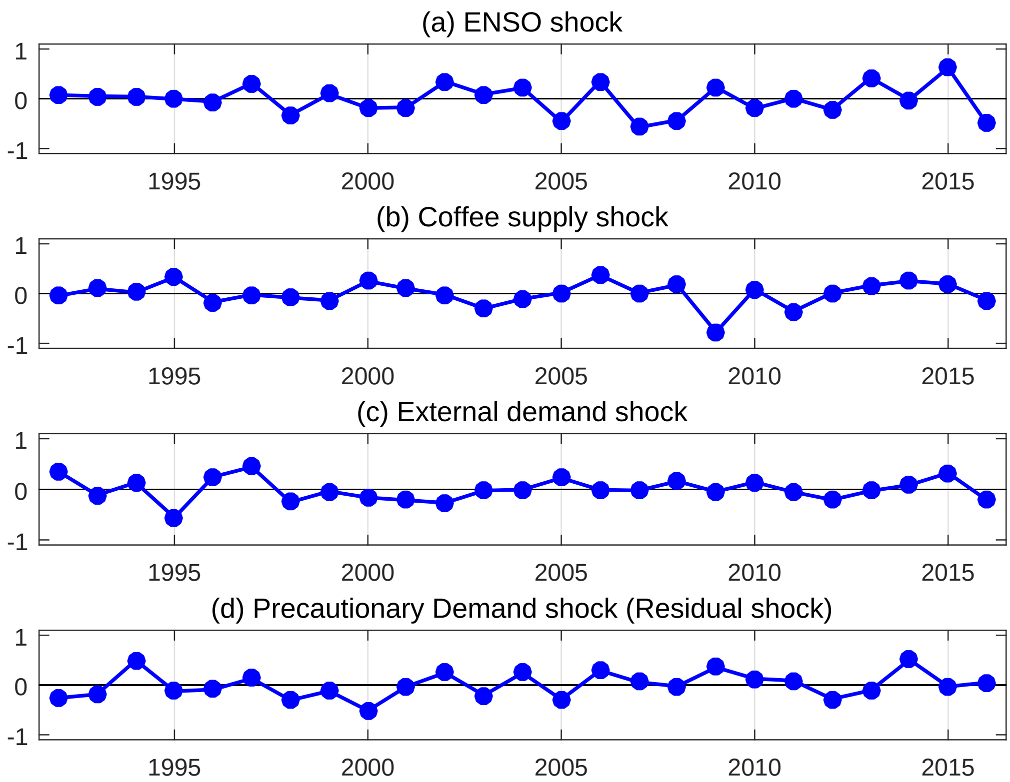
Figure 1: Real price of Colombian coffee: January 1990 - May 2016



Notes: The real price of coffee (RPC_t), expressed in 2016:5 U.S. $ per pound, has been obtained by deflating the nominal price (PC_t) using the Consumer Price Index (CPI_t): $RPC_t \equiv PC_t \times (CPI_t/CPI_{2016:5})$.

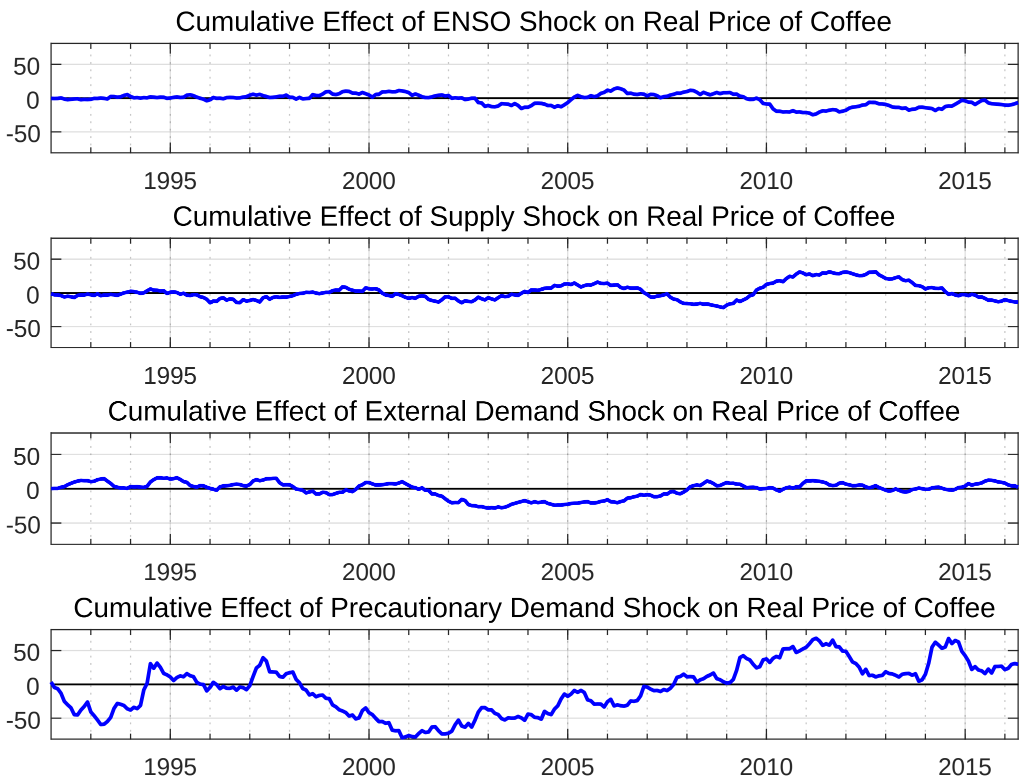
Source: Colombian Coffee Growers Federation (PC_t) and Federal Reserve Bank of St. Louis (mnemonic: CPIAUCSL).

Figure 2: Structural shocks: 1992 - 2016.



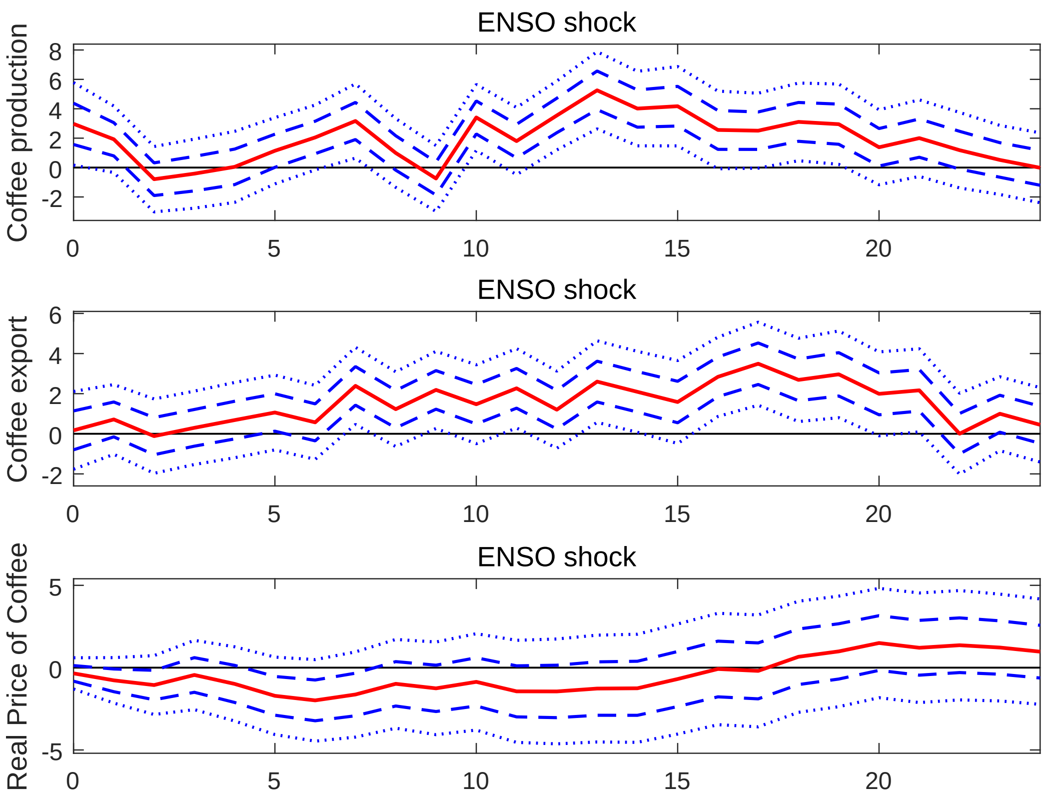
Notes: Structural shocks derived from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016.. Structural shocks are averaged at annual sampling frequency.

Figure 3: Historical decomposition of the real price of Colombian coffee: 1992:1 - 2016:5.



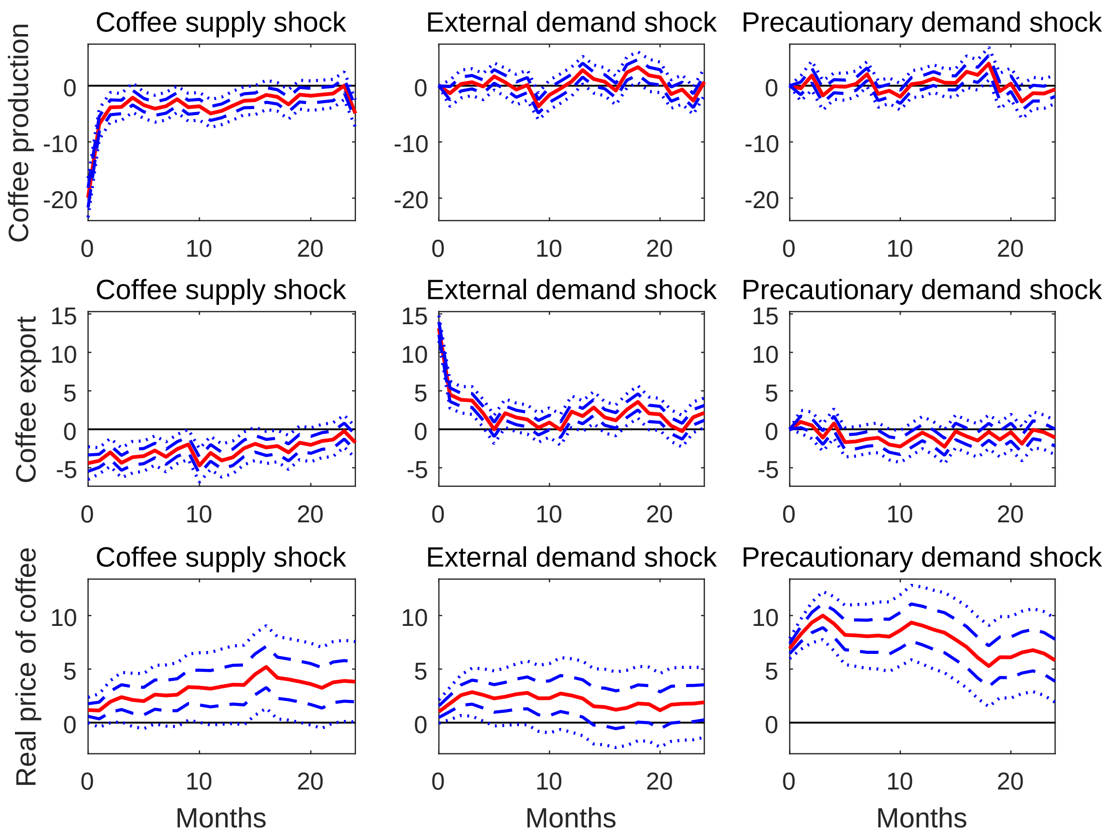
Notes: Historical decomposition derived from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016.

Figure 4: Impulse responses to a positive ENSO shock.



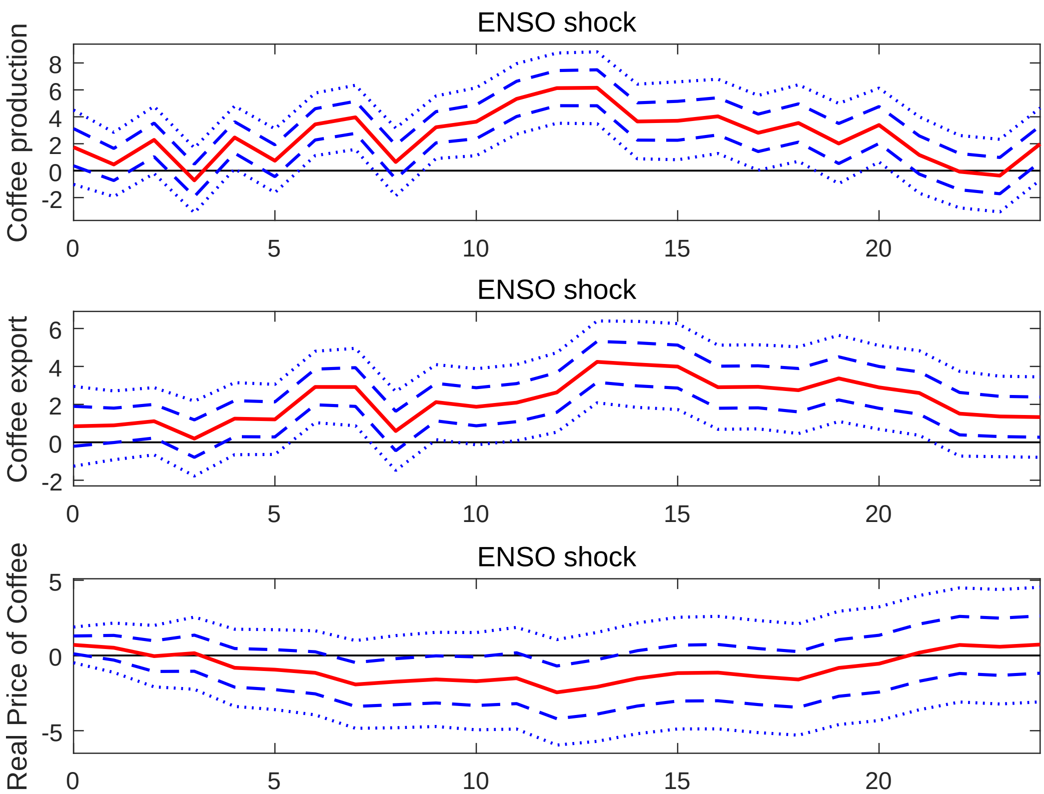
Notes: Impulse responses to a one-standard deviation ENSO (SST) shock (continuous line), with one- and two-standard error bands (dashed and dotted lines, respectively) from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016.

Figure 5: Impulse responses for the Colombian coffee market.



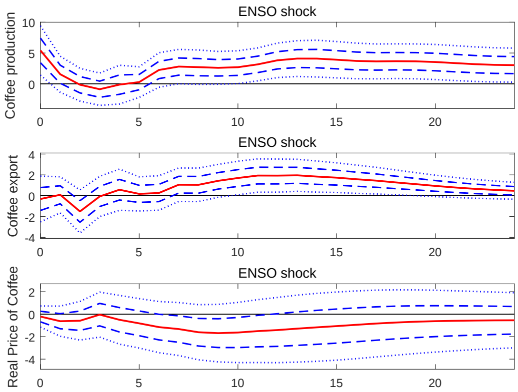
Notes: Impulse responses to one-standard deviation structural shocks (continuous line), with one- and two-standard error bands (dashed and dotted lines, respectively) from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016.

Figure 6: Impulse responses to a positive ENSO shock using SOI.

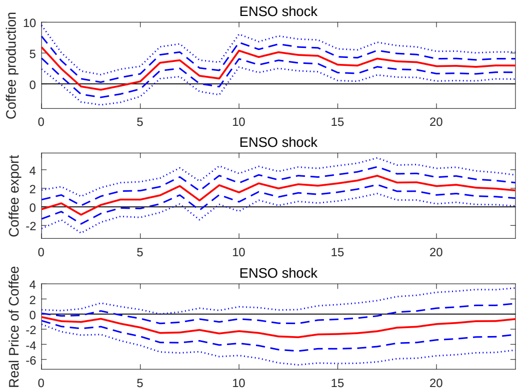


Notes: Impulse responses to a one-standard deviation ENSO (-SOI) shock (continuous line), with one- and two-standard error bands (dashed and dotted lines, respectively) from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016.

Figure 7: Impulse responses to a positive ENSO shock from VAR(6) and VAR(12) models.



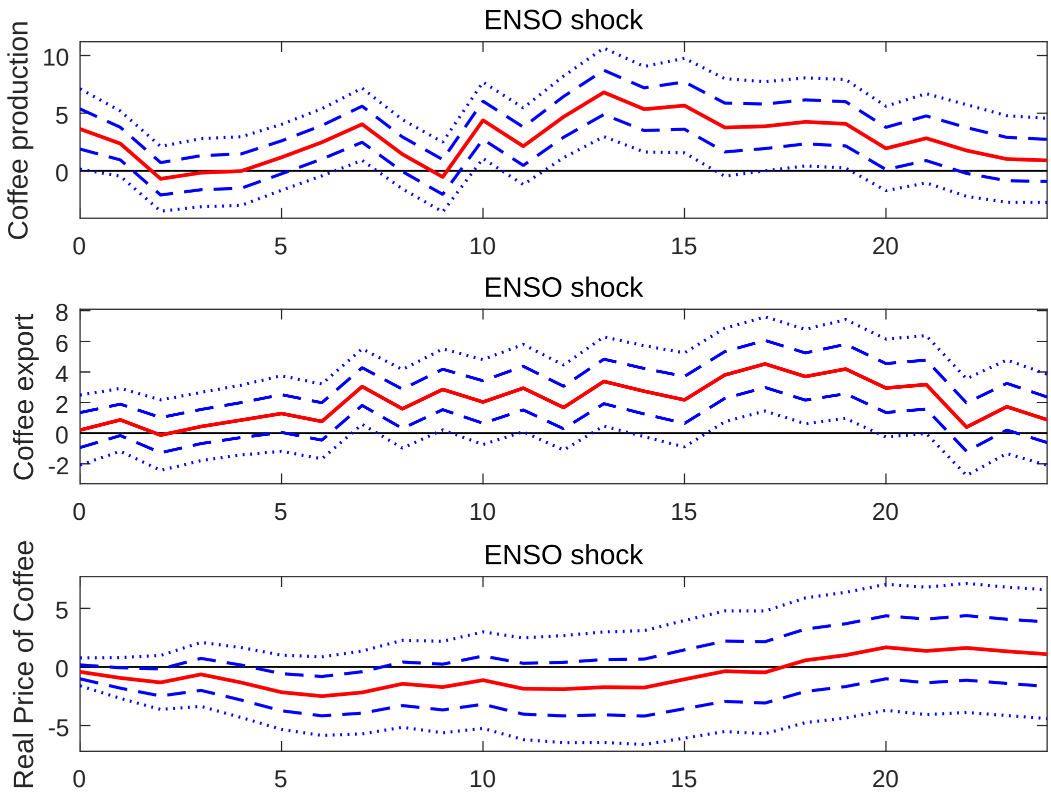
(a) IRF based on VAR(6)



(b) IRF based on VAR(12)

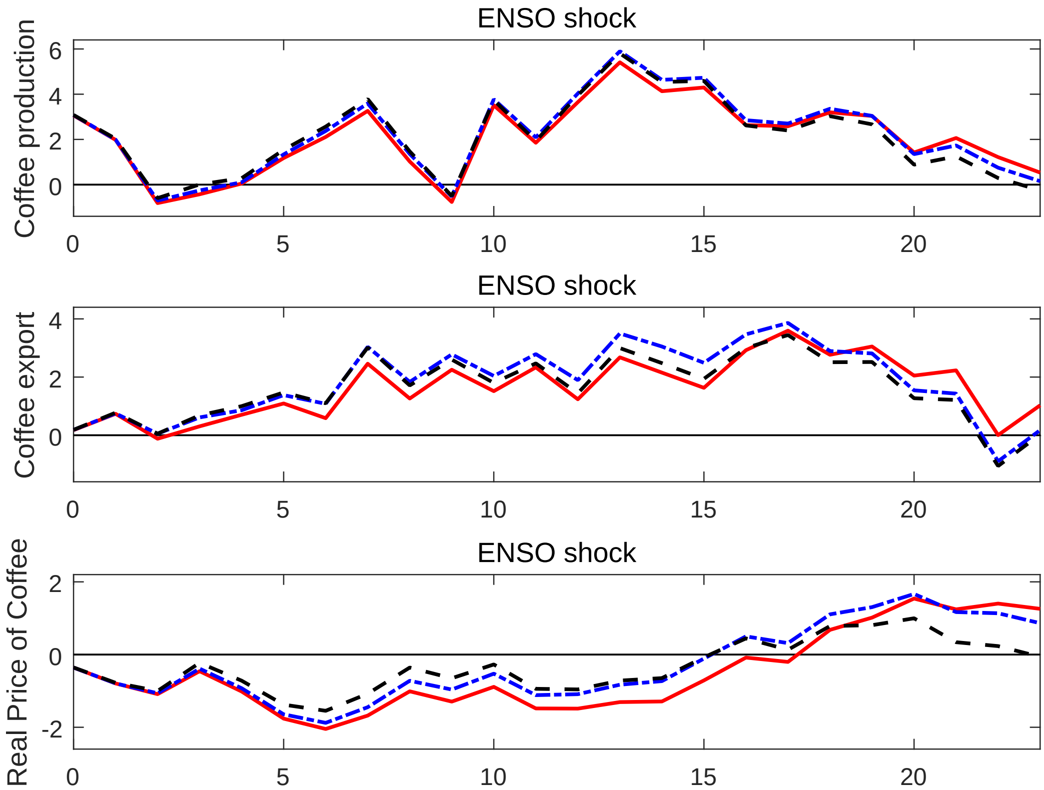
Notes: Impulse responses to one-standard deviation structural shocks (continuous line), with one- and two-standard error bands (dashed and dotted lines, respectively) from the estimation of (a) VAR(6) and (b) VAR(12) models using monthly data over the period January 1990 - May 2016.

Figure 8: Impulse responses to a positive ENSO shock with sst_t strongly exogenous.



Notes: Impulse responses to a one-standard deviation ENSO (SST) shock (continuous line), with one- and two-standard error bands (dashed and dotted lines, respectively) from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016. The reduced-form of the VAR(24) model is estimated with Iterated Feasible GLS.

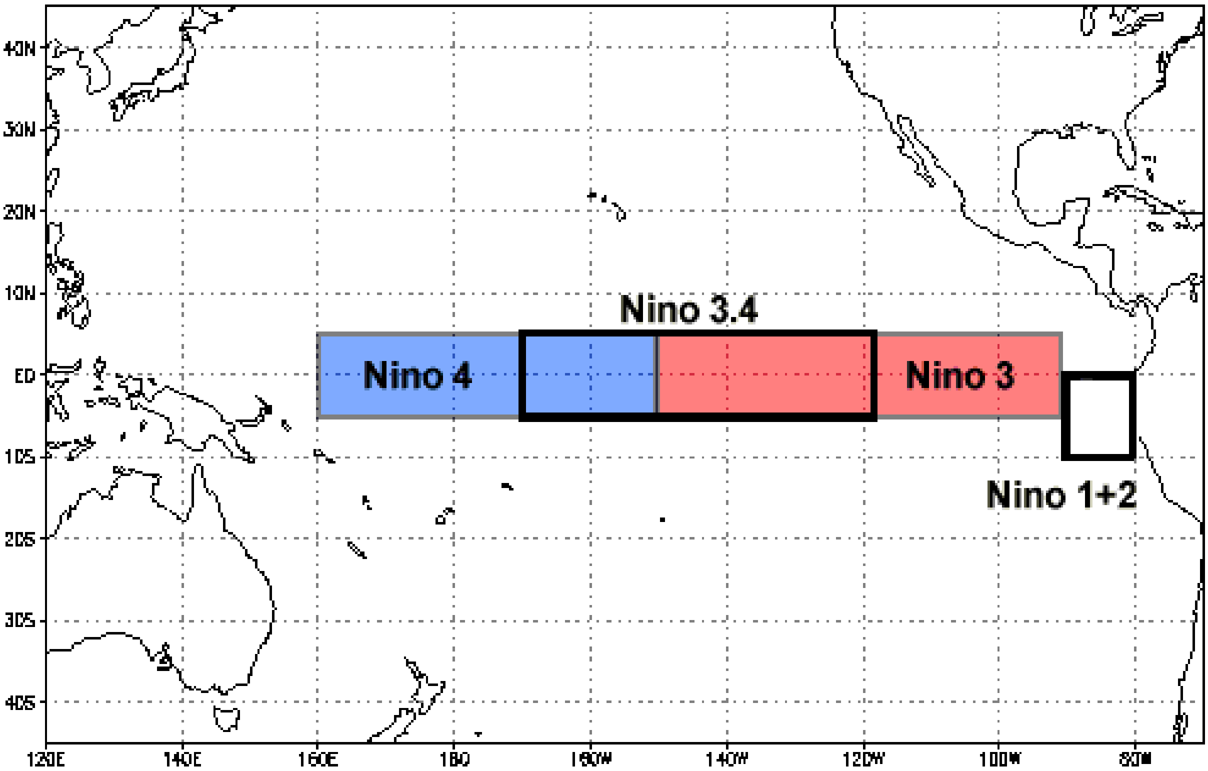
Figure 9: Impulse responses to a positive ENSO shock with additional exogenous variables.



Notes: Impulse responses (IRFs) to one-standard deviation structural shocks from the estimation of a VAR(24) model using monthly data over the period January 1990 - May 2016. The continuous lines denote IRFs derived from the original specification in Section 5. Dashed-dotted lines denote IRFs obtained by adding to the model the lagged real price of Brazilian coffee as an exogenous variable. Dashed lines denote IRFs obtained by adding to the model the lagged value of the average price of Other Milds, Brazilian Naturals and Robusta coffee as an exogenous variable. All price series have been converted from nominal to real terms using CPI data, transformed into logs and expressed in percent deviation from their sample average.

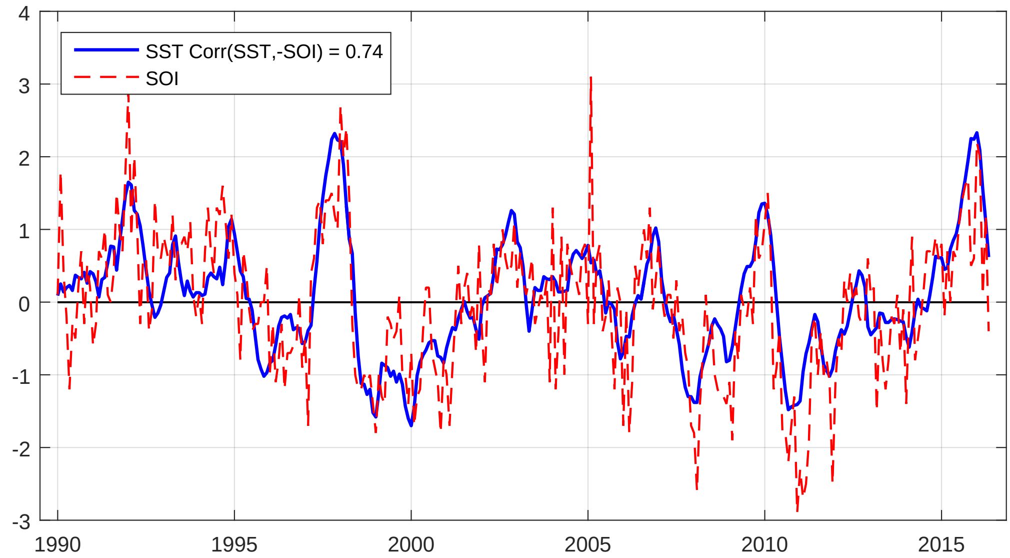
Appendix

Figure A1: The “Niño 3.4 region”



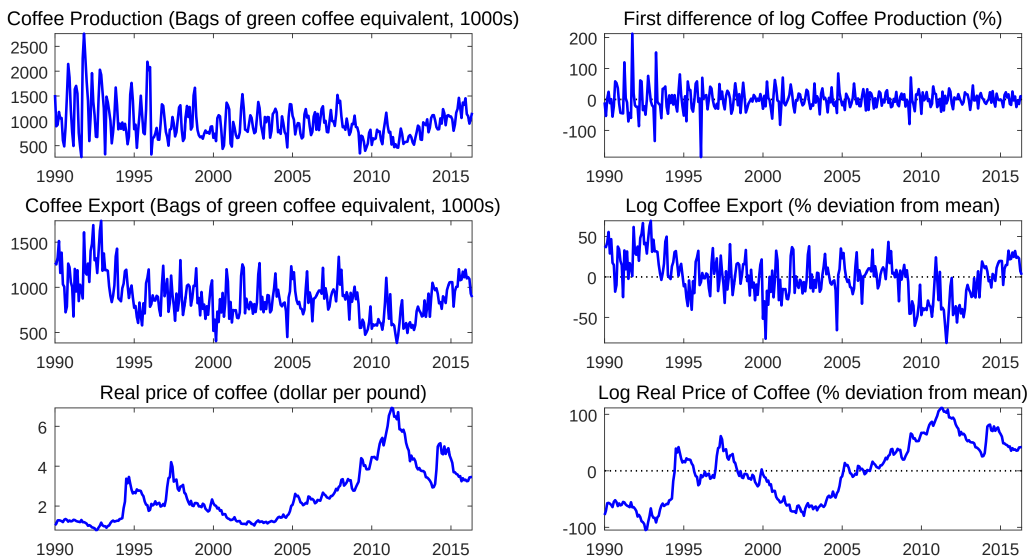
Source: National Oceanic and Atmospheric Administration (NOAA).

Figure A2: Sea Surface Temperatures and Southern Oscillation Index: 1990:1 - 2016:5.



Notes: Sea surface temperature (SST) anomalies in the "Niño 3.4 region" and the (negative of) Southern Oscillation Index (SOI). Prolonged periods of negative (positive) SOI values coincide with abnormally warm (cold) ocean waters across the eastern tropical Pacific, which are typical of El Niño (La Niña) episodes. Therefore, we plot -SOI and SST, so that positive (negative) values of both variables are associated with El Niño (La Niña) episodes.
Source: National Oceanic and Atmospheric Administration (NOAA).

Figure A3: Production, export and real price of coffee in Colombia: 1990:1 - 2016:5.



Notes: all variables are monthly and span January 1990 - August 2015. The left column of the plot shows the original variables, while the transformed variables - used in the estimation of the Structural VAR model - are reported in the right column. Production, export and price of coffee in Colombia are provided by the Colombian Coffee Growers Federation. The price of coffee has been converted from nominal to real terms using CPI data sourced from the Federal Reserve Bank of St. Louis (mnemonic: CPIAUCSL).

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