Estimating Price Elasticities of Supply for Cotton: A Structural Time-Series Approach

Ben Shepherd

Commodities and Trade Division, FAO

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Ben Shepherd
*Groupe d'Économie Mondiale (GEM), Sciences Po, Paris**
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* benjamin.shepherd@sciences-po.org

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ABSTRACT

The Kalman Filter is used to estimate a structural time-series model of cotton supply for 30 countries and 16 aggregated regions. Estimated short run supply elasticities with respect to the world price are presented for all 46 countries and regions. While they are broadly within the expected range in light of previous work, they indicate extensive cross-country and regional heterogeneity, as well as considerable parameter uncertainty in some cases. Finally, some proposals are made for incorporating both the core estimates and their sampling distributions into applied equilibrium models.

Keywords: Cotton; price elasticity of supply; structural time-series model; Kalman Filter.

JEL Codes: Q11; C22.

RÉSUMÉ

L'auteur utilise le filtre de Kalman pour calculer un modèle structurel de série chronologique de l'offre de coton pour 30 pays et 16 régions agrégées. Des estimations des élasticités de l'offre à court terme sont présentées pour les 46 pays et régions. Bien que répondant généralement aux estimations d'études préalables, elles indiquent une grande hétérogénéité entre pays et régions, de même que, dans certains cas, une forte incertitude quant aux paramètres. L'étude conclut par quelques propositions visant à incorporer les estimations centrales et leurs distributions d'échantillonnage à des modèles d'équilibre appliqués.

RESUMEN

Se utilizó el Filtro Kalman para estimar un modelo estructural de series cronológicas de la oferta de algodón de 30 países y 16 regiones en total. Se presentan las elasticidades estimadas de la oferta en el corto plazo con respecto al precio mundial de los 46 países y regiones. Si bien se encuentran claramente dentro de los márgenes esperados a la luz de trabajos anteriores, indican una amplia heterogeneidad entre países y regiones, así como una considerable incertidumbre de parámetros en algunos casos. Finalmente, se plantean algunas propuestas para incorporar las estimaciones básicas y sus distribuciones de muestreo a modelos de equilibrio aplicado.

CONTENTS

This paper was prepared for the Commodities and Trade Division, FAO. Sincere thanks (with the usual disclaimer) to Renato Flores and seminar participants in Rome for very helpful comments on a previous draft. Needless to say, the views expressed in this paper are those of the author only and do not represent those of any organization or its member countries.

Ben Shepherd,
Groupe d'Économie Mondiale (GEM), Sciences Po, Paris,
benjamin.shepherd@sciences-po.org

1 INTRODUCTION

FAO (2004) sets out a selection of the main problems that have confronted analysts in recent attempts to model policy scenarios of importance for the world cotton market. The authors highlight the significant impact of different supply (and demand) elasticities on the final results of quantitative modelling exercises, both as regards market outcomes and welfare changes, and in distributional terms (see also Shui, 2004).

The present paper contributes to helping resolve these difficulties in three ways. Firstly, it attempts to account more fully for the time series properties of relevant price and quantity data, and thereby produce technically more robust estimates of supply elasticities. Secondly, by highlighting the parameter uncertainty surrounding estimates, it helps provide a stronger basis for sensitivity analysis in applied policy modelling. Finally, the econometric exercise undertaken here applies the same estimating framework across a considerable number of countries (30) and aggregate regions (16), thereby favouring consistent and comparable results.

After briefly reviewing previous estimation work in Section 2, a benchmark empirical model that pays special attention to the time series properties of the data is set out in Section 3. Data and estimation results are discussed in Section 4. Section 5 concludes, with some suggestions for incorporating these results into applied partial and general equilibrium models.

2 LITERATURE REVIEW

It is noteworthy that despite the importance cotton has recently assumed in international agricultural policy modelling, there are relatively few detailed, cross-country econometric studies of supply elasticities for this product. Table 6 presents a selection of the most relevant results from that literature, drawing on papers with both regional and global perspectives; elasticity values used in the ATPSM models are presented in the first column as a benchmark and link to applied work.[1]

General approach

In all papers referred to in Table 6, estimation is conducted using one of innumerable variations on a basic model of cotton supply, in which logarithms of quantities (or areas) are modelled as a function of current and/or lagged output and input prices, also in logarithms. Some studies explicitly augment this with expectations and adjustment mechanisms à la Nerlove, implying the presence on the right-hand side of lagged quantities or areas as well (see Askari & Cummings, 1977, for a general survey). A reduced-form estimating framework that broadly encompasses the different formulations used in applied work—keeping to a pure time-series perspective, rather than assuming panel data—would therefore take the form of equation (1), in which Q^s is the quantity of cotton supplied (or area planted) in a given period, P^c is the price of cotton, P^o refers to a vector of prices for goods that are substitutes or complements with cotton in consumption, P^i is a vector of input prices, μ is a trend, the D terms are dummies designed to capture various forms of structural change and ω is an error term:

$$\text{(1)} \qquad \log\left(Q_t^s\right) = \mu(t) + \alpha_1 \log\left(Q_{t-1}^s\right) + \sum_{i=0}^{p} \beta_i \log\left(P_{t-i}^o\right) + \sum_{j=0}^{q} \gamma_j \log\left(P_{t-j}^i\right) + \sum_{k=0}^{r} \delta_k D_k + \sum_{l=0}^{s} \varepsilon_l^s \log\left(P_{t-l}^c\right) + \omega_t$$

In order to operationalize (1), a number of preliminary questions need to be addressed. Will world or local prices be used? Which products will be included in the vectors of input and output prices? By how many periods will prices be lagged? How will the trend be specified? How will structural change be identified and accounted for? Once these questions are resolved, there is obviously an additional issue to consider: namely, use of an econometric methodology that takes appropriate account of both model and data structure. As will be seen in the brief discussion that follows, the existing literature has taken various approaches to dealing with these questions.

[1] Estimates from Sumner (2003)—drawn in turn from the FAPRI model and database—are presented in Table 6; however, they cannot be discussed in detail since the estimation procedure is not reported in detail.

Cross-country and regional studies

Gillson *et al*. (2004) is the most recent cross-country study in this area, presenting estimated elasticities for 26 producer countries over the period 1969-2001 using a Bayesian panel methodology. In terms of equation (1), the authors effectively rearranged terms so as to have supply appear in first differences on the left-hand side; assuming that the expectations parameter is non-zero, this formulation implicitly assumes that the supply series is stationary. The trend was specified as being linear or quadratic, world prices were used both for cotton and competing goods (maize, rice, wheat and soy beans), input prices were excluded and price terms were lagged by a single period.[2] It is not clear to what extent structural change was allowed for in the form of intervention terms, but for a subset of countries estimation was carried out both over the full sample (1969-2002) and over a much shorter sub-sample (1990 onwards). It is important to note that in order to avoid negative estimated elasticities, the authors effectively constrained model parameters so as to exclude that possibility;[3] as they acknowledge (p. 95), such a procedure inevitably results in estimates that are more elastic than they would have been had the constraint not been imposed.

An earlier paper by Coleman & Thigpen (1991)—also summarized in Table 6—developed an integrated econometric model of the world cotton market, covering producing regions in eight countries (each estimated separately). Specifications varied somewhat across regions, but cotton acreage was generally modelled as a function of world or domestic prices of cotton, competing crops (sorghum, rice and coarse grains) and inputs (irrigation and fertilizer), a time trend and lagged acreage. Yields were modelled as a function of acreage, weather conditions, a time trend and dummy variables. Both yield and area equations included impulse dummies to account for outliers, but do not seem to have taken systematic account of structural change. In both cases, it was implicitly assumed that the relevant processes were stationary. The authors found that elasticities estimated using the world price were often statistically insignificant, and therefore placed most weight on results obtained using domestic prices.

Hugon (2005) and Gilbert & Modena (2004) have recently presented elasticity estimates for West African producers. The precise model used in the first of these two papers is unfortunately not fully specified; in any case, only three out of 14 reported supply elasticities are statistically significant. The second paper, on the other hand, obtained considerably more solid results, using quite a different approach from Gillson *et al*. (2004) or Coleman & Thigpen (1991). The acreage function was specified in terms of unobserved components (a "smooth" stochastic trend and a stationary autoregression) augmented by a lagged cotton price term (the world price converted to local currency, and deflated using the local deflator). Yields were modelled in terms of similar unobserved components and lagged acreage. Both equations included various types of intervention terms to account for outliers and possible structural change. Estimation in both cases was via the Kalman Filter, with the results from the two models being combined to give an overall supply elasticity. Importantly, stationarity was not assumed but rather was treated as a special case of the "smooth" stochastic trend formulation (i.e., a deterministic trend). Price elasticities were found to be statistically significant in three out of five cases, and marginal in the other two (at the 15 percent level). The estimate for Chad was, however, constrained so as to result in a positive overall elasticity.

Single-country studies

Another strand of the literature has concentrated on producing estimates for single countries—most often the United States of America—paying particular attention to the possible impact of relevant policy measures. Beach *et al*. (2002) is one example of such an approach, in which a supply equation for the United States was estimated in the context of an integrated econometric model of the cotton market that was then used to assess the impact of US promotion, research and price support

[2] In sensitivity analysis, the authors experimented with numerous other formulations: domestic (rather than world) prices, additional lags and different trend specifications. None of these changes was found to have a significant impact on results.

[3] To be precise, the constraint was implemented through rejection during Gibbs-sampling, rather than through direct algebraic means.

programmes. In terms of equation (1), the dependent variable was US quantity supplied, while on the right-hand side the authors used averaged real US futures prices for cotton, a lagged index of real input prices and a linear time trend. Estimation was by OLS, and the authors found elasticities ranging between 0.45 and 0.49; they cited previous estimates ranging between 0.3 and 0.9.

In a panel data framework, Lin *et al*. (2000) used acreage shares on the left-hand side of equation (1), with adjusted futures prices for cotton and competing crops (corn, wheat, sorghum and soy beans) on the right-hand side. They estimated the US supply elasticity at 0.47, and argued that it increased under the 1996 Farm Act. (In fact, it is not clear whether the change in question is statistically significant and to what, if any, extent it is related to different estimation methodologies.)

Consolidation

While the above review does not claim to be exhaustive, it nonetheless captures the general thrust of the more recent contributions to the literature in this area. It can be seen that existing elasticity estimates are quite patchy, in the sense that only a relatively small number of countries are covered in each study (with the exception of Gillson *et al*. (2004), who analysed 26 countries). This means that applied equilibrium models usually need to draw elasticity estimates from multiple sources, with corresponding mixing of methodologies and specifications. The flip-side of this point is that when multiple estimates for a single country are available, there are often significant discrepancies amongst them (see Table 6); this is particularly the case for developing countries and regions of particular analytical interest, such as West Africa. By contrast, countries for which no estimate is available must either receive some average value taken from the existing literature, or simply be specified in terms of the researcher's priors.

Secondly, it emerges from the literature review that the choice of price series (world or domestic) is potentially crucial. Given that producers in numerous countries are to some extent insulated from world prices by policy interventions, it seems likely that world price elasticities will be lower than domestic price ones. In extremely distorted markets, however, world price elasticities may prove difficult to reliably estimate, exactly because the distortions are maintained in order to loosen the link between local production and world prices. That problem could conceivably be resolved by using domestic prices, but at the cost of having to deal with difficult issues of conversion factor and choice of deflator; such questions are all the more problematic for countries that have known periods of very high inflation, which is the case for some major cotton producers. The possibility is very real of introducing inordinate amounts of noise into the dataset, and thereby making estimates less, rather than more, efficient.

Ultimately, the choice of which price series to use must be a pragmatic one. One relevant piece of information is that the most recent cross-country paper (Gillson *et al*., 2004) reported superior results using world, rather than domestic, prices. But a second and even more important consideration stems from the principal use to which such elasticity estimates will be put: applied partial and general equilibrium modelling. Standard partial equilibrium models for cotton (Gillson *et al*., 2004; Goreux, 2004; Tokarick, 2003) tend not model world to producer price transmission in detail. The same is true even in larger cross-country models like ATPSM (Peters & Vanzetti, 2004), in which domestic prices are taken as being identical to world prices except to the extent that directly quantifiable wedges exist in terms of the policy measures (tariffs, quotas and some subsidies) being modelled. These models generally do not contain separate data on domestic prices, and no allowance is made for domestic margins, transactions costs or other policy interventions that might loosen the link between world and domestic prices (and, implicitly, between world prices and domestic production). While general equilibrium models often incorporate greater detail in terms of policy measures (see e.g., Tokarick, 2003; Keeney & Hertel, 2005), similar comments nonetheless apply, in particular where developing country producers are concerned.

It seems clear that the elasticity parameters fed into such models should reflect these salient features of their design. This is another reason—in addition to the practical advantages highlighted by Gillson *et al*. (2004)—for focussing on elasticities with respect to world, not domestic, prices. (Of course, this is not to say that this position might not need to be rethought at some point in the future, if changes were to be made to the way in which this class of models is set up.)

The issue of policy interventions decoupling world and producer prices is also of potential importance in another respect. An application of the Lucas (1976) critique to this type of analysis could give rise to concerns that estimated elasticities are not necessarily robust to changes in policy regime. While it would certainly be desirable to take account of this problem at the econometric stage, that task is rendered difficult by the theoretical structure of commonly used models (see above) as well as the lack of comprehensive, consistent and comparable time series data on policy distortions in producing countries. For the moment, then, cross-country econometric work is more or less constrained to proceed on the assumption that estimated elasticities do not change "too much" as a result of a Lucas-type effect. This can perhaps be improved upon for individual countries, but at the cost of losing direct comparability with estimates for other countries.[4]

Finally, it is noteworthy that existing estimates have made particular assumptions regarding the time-series properties of price and quantity data. Specifications have variously included linear and quadratic deterministic trends (in levels or in first differences) and "smooth" (stochastic) trends, but in almost all cases—Gilbert & Modena (2004) is the exception—the quantity and price data have been assumed to be stationary. This is an important question, since there are some suggestions in the literature that unit roots could in fact be present: e.g., Baffes & Ajwad (1998), Baffes & Gohou (2005) and Shepherd (2004). It would therefore be desirable that the econometric methodology used to estimate supply elasticities properly take account of this issue, so as to avoid "spurious regression" problems that can arise when regressing one non-stationary series on another using conventional techniques. Three main approaches are potentially available for doing this: data transformation, cointegration and error-correction, and structural time-series modelling using the Kalman Filter.

Within the limits of what is practical given the present state of the data, the next Section deals with these three issues in the context of a structural time-series model of cotton supply.

3 A STRUCTURAL TIME SERIES MODEL OF COTTON SUPPLY

Specification of the trend function in equation (1) is of primary importance in determining the econometric approach to be adopted: if it is deterministic, some variant of OLS can likely be applied; if it is stochastic, either the data must be transformed so as to be stationary, or an alternative methodology must be used. One flexible way of approaching this question is to use a "local linear trend" specification (Harvey, 1989; Durbin & Koopman, 2001):

(2a) $\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t$

(2b) $\beta_t = \beta_{t-1} + \zeta_t$

Both ζ_t and η_t are assumed to be drawn from independent normal distributions, so the resulting trend is only deterministic if the variance of each disturbance term is zero (i.e., if $\sigma_\zeta^2 = \sigma_\eta^2 = 0$). If one or both of the variances are non-zero, then the trend is stochastic: either a random walk with drift ($\sigma_\zeta^2 = 0 \neq \sigma_\eta^2$), a "smooth" trend ($\sigma_\eta^2 = 0 \neq \sigma_\zeta^2$) or a double stochastic trend ($\sigma_\zeta^2 \neq 0, \sigma_\eta^2 \neq 0$). Regardless of the nature of the trend, the Kalman Filter can still be used to obtain maximum likelihood estimates of the relevant parameters. It is therefore not necessary to conduct unit root pre-tests before deciding on an estimation methodology, which is a distinct benefit in light of the well-known difficulties surrounding such tests (e.g., Maddala & Kim, 1998). Nor is it necessary to pre-test for cointegration. This is another good reason for preferring such an approach to either data transformation through differencing or cointegration-error correction models.

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[4] The US studies referred to above look at the quantity impacts of policy measures, but do not explicitly allow for the type of effect Lucas (1976) had in mind. McDonald & Sumner (2003) deal with the issue more squarely in a calibration-simulation framework. Subject to the data issues already noted, another promising option that would at least go part of the way to dealing with these problems might involve estimation of supply models with policy data and time-varying parameters (Sims, 1982). This could be practical in the US case, and perhaps also for the EU.

Combining the above trend specification with a trimmed down version of (1), a baseline empirical supply relation could be as follows (with all disturbances assumed to be independent and Gaussian):

(3a) $\log\left(Q_t^s\right) = \mu_t + \upsilon_t + \sum_{k=0}^{r} \delta_k D_k + \varepsilon^s \log\left(P_{t-1}^c\right) + \omega_t$

(3b) $\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t$

(3c) $\beta_t = \beta_{t-1} + \zeta_t$

(3d) $\upsilon_t = \rho \upsilon_{t-1} + \iota_t$ (where $0 < \rho < 1$)

For the reasons set out in the previous section, world prices will be used in (3a). Intervention terms (in equation (3a), the D parameters) are used to take account of possible structural change, as diagnosed using model residuals (Harvey, 1989; Durbin & Koopman, 2001; Koopman *et al*., 2000). It is important to note, however, that the elasticity parameter itself is interpreted in a short run sense, and is assumed to be constant over time.[5]

An autoregressive term is included in equations (3a-3d) to take account of additional short-term dynamics in the model, as in commonplace in this type of formulation. Prices of inputs and competing goods are excluded from the model on the basis that those series—as well as the relative weights producers give them when making production decisions—can be expected to vary over time in a complex way; such variation should be captured at least approximately by evolution in the trend.[6] Alternatively, if this is asking too much of the trend, then standard diagnostic tests could be expected to indicate a problem with model specification.

The two other major changes from (1)—use of only a single lag for prices and exclusion of lagged quantities—are based on empirical considerations. As in previous work (Gillson *et al*., 2004), additional lagged price terms were generally not found to be significant in preliminary work. The same was found for lagged quantities. In both cases, exclusion did not significantly affect estimates of other parameters and was therefore preferred on grounds of parsimony.

While the logic behind (3a-3d) is no different to what is to be found in previous work, the precise formulation—as well as the estimation method—are slightly more heterodox. However, the model is very similar to Gilbert & Modena (2004), the principal difference being the use of a local linear trend of which the "smooth" trend used by those authors is a special case. The responsiveness of US cotton exports to relative price movements and exchange rate volatility were investigated in a similar framework by Fadiga (2004). Two recent papers by Adhikari *et al*. (2005a, 2005b) go in the same direction for dairy, corn and soybeans, while Komaki & Penzer (2005) use a variation on the theme in which the price elasticity of dairy supply is assumed to be time-varying, based on a random walk.

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[5] In a previous draft of this paper, results were presented using a model in which the elasticity was allowed to vary over time as a random walk. Evidence was found to suggest that at least for some countries, such time variance in parameters might indeed be an important factor to take into account, as has already been suspected in the literature (Gillson *et al*., 2004). However, results were found to be sensitive both to specification and to initial numerical conditions. These factors—combined with the desire to ensure maximum comparability across countries—led to re-working the models imposing a fixed elasticity. Nonetheless, this seems a promising avenue for future research (cf. Komaki & Penzer, 2005 for dairy supply; and Hooper *et al*., 1998 for aggregate export/import elasticities).

[6] Implicitly, this is the approach taken in Gilbert & Modena (2004) and Komaki & Penzer (2005), though the authors do not motivate it in exactly this way.

4 DATA AND ESTIMATION RESULTS

Information on data and sources is presented in Table 1. To summarize, the model is estimated[7] over the period 1961-2004 for a set of 30 countries and 16 FAOStat regions, taking each country or region separately (i.e., without pooling). Country selection was based on total production in 2004, the aim being to cover all major cotton producers. The unavailability of consistent and sufficiently long series for cotton producing countries formerly part of the USSR meant that those countries (Kazakhstan, Tajikistan, Uzbekistan and Turkmenistan) could not be analysed individually. Regional-level aggregate data had to be used instead. All production data are taken from FAOStat, using a conversion factor of 1/3 to calculate lint equivalents from seed cotton figures. For the world price term, the IMF Liverpool Price is used.[8]

It is simple to rearrange equations (3a-3d) into a linear Gaussian state-space model of the following form (using appropriately dimensioned matrices):

$$\begin{aligned} y_t &= Z_t\alpha_t + X_t b + G_t u_t \\ \alpha_{t+1} &= T_t\alpha_t + H_t u_t \end{aligned} \tag{4}$$

With (3a-3d) expressed in this way, it can be seen that the trend, slope and autoregressive components are effectively treated as unobserved "state" variables (the α matrix in equation (4)) that describe the system's evolution over time. Their individual laws of motion are given in the second ("transition") equation, while their relationship to observed prices and quantities is governed by the first ("measurement") equation. With the model in state-space form—and assuming that Gaussian assumptions hold—the Kalman Filter offers an efficient estimating strategy, based on a system of recursions that can be used to obtain minimum mean squared error forecasts of the dependent variable and the unobserved states, as well as to calculate maximum likelihood estimates of unknown parameters such as the disturbance variances. Full technical details of the Kalman Filter can be found in standard sources such as: Harvey (1989), Durbin & Koopman (2001), Koopman *et al*. (2000), Hamilton (1994) and Lutkepohl (2005).

Estimation results are presented in Table 2 (individual countries) and Table 4 (aggregate regions), which show estimated parameters (disturbance variances and the short run elasticity), along with estimated final states (the trend, slope and autoregression). Details are also provided of any intervention terms included in the model to take account of structural change.[9] All models converge rapidly, and the standard diagnostics presented in Tables 3 and 5 do not indicate any serious problems in terms of the specification adopted. A handful of models display weak evidence of heteroskedasticity or autocorrelation, but in only one case is the relevant null hypothesis rejected at the 1 percent level. Goodness-of-fit as measured by Rd2 (Harvey, 1989) averages 0.48 (upper bound at unity), and is in all cases positive (i.e., all estimated models "beat" a random walk with drift model).

Thirty of the 46 elasticity estimates presented in Tables 2 and 4 are statistically significant at the 10 percent level. Thirty-nine estimates carry the expected positive sign and have an economically sensible magnitude, while only seven (four countries and three aggregate regions) carry negative signs. These are quite respectable results when set beside the existing literature, in particular since no parameter constraints have been applied. Given the history of strongly interventionist policy stances in some producing countries, it is not too surprising that there should be some statistically insignificant or even negative estimates with respect to the world price. When it comes to partial and general equilibrium

[7] All calculations were performed using STAMP 6.30 (Koopman *et al*., 2000). The dataset is available on request.

[8] It could be argued that in light of quality and other differences amongst exporting countries, it might be more appropriate to use Cotlook A component indices rather than the Liverpool Price. However, this once again introduces a level of detail that is usually not reproduced in applied equilibrium models. In the interests of consistency, it is therefore not attempted here.

[9] The auxiliary residuals, along with standard significance tests, were used to set up appropriate intervention terms; see the general Kalman Filter sources cited in the text for further details.

modelling, however, negative and insignificant estimates are genuinely troublesome; some suggestions for dealing with them are given in Section 5.

In terms of magnitudes, the estimated elasticities generally appear reasonable, although they are towards the low end of expectations. The cross-country average is around 0.3 when all individual country results are taken into account, or 0.5 when only statistically significant elasticities are included in the calculation. The regional distribution of price-responsiveness is quite marked, with Latin America and Asia noticeably more sensitive to world price changes than are other major producing regions, including Africa.

Table 6 compares the present paper's estimates with the elasticities used in Poonyth *et al*. (2004) and estimates obtained from the econometric studies reviewed in Section 2. It would appear that the elasticities built into ATPSM are on the high side when compared with econometric estimates (both this study and others). Leaving those numbers to one side, it can be seen that the estimates presented here are in general well within the bounds established by previous econometric work, in particular once the uncertainty inherent in the estimation process is taken into account. Table 6 makes this uncertainty apparent by presenting three separate estimates for each elasticity, namely the mean and suggested upper and lower bounds (calculated as two standard errors on each side of the mean, representing an approximate 95 percent confidence interval).

Nonetheless, a few notable cases deserve further comment. Firstly, the core estimate for the United States (0.16) is lower than anticipated, but would perhaps be consistent with significant policy interventions tending to distort the transmission of world price signals. In any case, this result needs to be kept in perspective: when 95 percent bounds are put around the core estimate, the identified range is quite sensible—though admittedly wide—when compared with existing work (see above).

Estimated supply elasticities for West African countries are also towards the bottom bound of the range established in the papers considered in Table 6. However, the present paper's estimates are not too far away from those reported by Gilbert & Modena (2004), or from certain results in Hugon (2005). Similarly, Fadiga *et al*. (2004) use a supply elasticity of 0.01 for African cotton.

Finally, it is worthwhile highlighting the wide variety of trend specifications—deterministic, random walk with or without drift, random walk in slope and double stochastic—that are apparent in Table 6. In other words, quantity series from different countries have quite different statistical properties, including both stationary and non-stationary cases. In light of the difficulties that non-stationary (or mixed stationary and non-stationary) data pose for conventional regression techniques, these findings suggest that there may be considerable scope in the future for expanding the use of more flexible methodologies—such as the Kalman Filter—when estimating supply functions.

5 CONCLUSIONS

This paper presents a new set of world price elasticity estimates for cotton supply, based on a structural time-series model estimated using the Kalman Filter. One important advantage of such an approach is that it can deal with both stationary and non-stationary data, while avoiding the need for transformations that can potentially reduce cross-country comparability when dealing with a mixture of stationary and non-stationary models. It also avoids the need for pre-testing, which has well-known limitations in the context of cointegration and error-correction models. As noted above, this seems to have been a significant empirical advantage in this case.

The results reported here suggest that countries differ significantly in their supply responsiveness to world price changes, and that parameter values used in applied modelling work may need to be adjusted in consequence. Moreover, the degree of uncertainty surrounding parameter estimates is sometimes considerable; this has obvious implications for the uncertainty surrounding estimates of market outcomes or welfare changes resulting from different policy scenarios.

Looking towards the future, it is worth making two points about these results from the perspective of a "consumer" (e.g., an applied trade policy modeller). Although the functional forms used in this paper have been kept intentionally simple and general, they will not always correspond with the functional forms used in computable partial or general equilibrium models. Each consumer will need to confront the issue of whether the functional forms used in estimation are sufficiently close to those used in her/his model as to justify using such "off the shelf" parameter estimates. If the differences in functional form are deep and many, then the modeller would be well advised to re-estimate from scratch, embedding the new model directly in an econometric framework. This is a straightforward point, but it seems worth stressing in light of the variety of modelling approaches currently on offer, as well as the importance that cotton sector models can assume in public policy terms.

Secondly, the question of negative elasticity estimates needs to be addressed. The applied modeller has essentially two options in this regard. One is to replace negative country estimates with appropriate regional estimates, nearly all of which are positive. This is a pragmatic way of achieving "sensible" results in applied work, albeit at the cost of some loss in detail. A second option is to link this question to the kind of sensitivity analysis described below, in which a large number of model outputs are produced by resampling from parameter estimates so as to produce a distribution of final results. In such a methodology, it is possible to truncate the distribution from which estimated negative parameters are assumed to have been drawn, such that values below zero are ignored (cf. rejection in the Bayesian approach to estimation used by Gillson *et al*., 2004 and Balcombe, 2005). It is suggested that such an approach will still produce "sensible" model outputs, while giving due weight to the difficulties encountered in estimation which stem, after all, from the data themselves. Table 6 shows one very simple way of operationalising this idea, namely calculating confidence intervals as normal for negative parameters, but truncating them at zero.

A third important issue for the consumer is how best to take account of the uncertainty surrounding elasticity estimates. When producing "best-guess" estimates of policy impacts, mean parameter estimates reported in Table 6 could be used (where negative values have been replaced by zeros). However, it is suggested that such estimates should systematically be framed in terms of their sensitivity to changes in parameter values. One option is to construct appropriate confidence intervals using the standard deviation of the parameter estimate (reported in Tables 2 and 4); this is the approach adopted in Table 6. A more sophisticated alternative is to create a direct link between the econometric framework and the applied equilibrium model, and to use a resampling and/or stochastic simulation strategy (i.e., making a large number of draws from the sampling distribution of the relevant parameters and producing a correspondingly large number of policy impact estimates). Both methods should be computationally feasible. It would seem particularly important that this kind of systematic sensitivity analysis be pursued in an area as controversial as cotton sector modelling, especially given the importance that divergent impact assessments have assumed in the public arena. Again, this is a straightforward idea, but one that has gained widespread acceptance in applied trade policy work only comparatively recently (cf. Hertel *et al*., 2004; Keeney & Hertel, 2005).

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TABLES

Table 1: Data and sources

Variable	Description	Year	Source
Production	Total cotton production, expressed in lint-equivalent with LE = Seed cotton / 3, and converted to lb.	1961-2004 (annual)	FAOStat and own calculations
Price	Liverpool cotton price in c/lb.	1961-2004 (annual)	International Financial Statistics and own calculations

Table 2: Estimation results – countries

Country	Disturbance Variances				Final State Coefficients			Intervention Terms	Elasticity
	σ_{ω}^{2}	σ_{η}^{2}	σ_{ζ}^{2}	σ_{ι}^{2}	μ_t	β_t	ν_t		ε^{s}
Argentina	0	0.032704	0	0.044388	15.007***	-0.021231	0.02365		1.044***
					1.0351	*0.028832*	*0.1733*		*0.25076*
Australia	0	0.074547	0	0.012584	18.657***	0.091559**	0.00671	1965(L)	0.462*
					1.0490	*0.043184*	*0.10696*		*0.25348*
Benin	0	0.007751	0.002384	0.013061	19.513***	0.019774	-0.0243	1972(S), 1979(L), 1981(S), 1982(L), 1987(L)	0.016534
					0.67453	*0.083731*	*0.09258*		*0.16666*
Bolivia	0.00212	0.046943	0.008748	0	14.459***	0.0019735	0	1973(S), 1985(L), 1989(L), 1991(L)	0.82869***
					0.84839	*0.15978*	*0*		*0.20466*
Burkina Faso	0	0	0	0.057061	19.636***	0.083049***	0.17691	1968(L)	0.011178
					0.79035	*0.0066847*	*0.13673*		*0.17875*
Brazil	0	0.036227	0	0.001547	19.108***	0.20078***	-0.00486	1996(S)	0.62581***
					0.68176	*0.069135*	*0.14999*		*0.16031*
Cameroon	0	0.000879	0	0.020809	17.476***	0.060519***	-0.08996	1971(L), 1973(L)	0.38555***
					0.55388	*0.0068486*	*0.09285*		*0.13081*
Chad	0	0	8.86E-06	0.022979	17.804***	0.025623**	0.16236	1979(L), 1983(O), 1987(L), 1997(O)	0.23854**
					0.47315	*0.010386*	*0.07301*		*0.11259*
China	0.001331	0.014398	0.00129	0.000104	22.745***	0.069196	0.00072	1963(L), 1985(L), 1991(O)	0.14436
					0.46954	*0.071477*	*0.01028*		*0.11345*
Colombia	0	0.035955	4.28E-05	0	16.287***	-0.035334	0	1982(L), 1984(L), 2003(L)	0.54017***
					0.64646	*0.038744*	*0*		*0.15577*
Côte d'Ivoire	0	0	0.000151	0.021019	19.922***	0.030001	-0.20797	1963(O), 1967(L), 1992(L)	-0.12173
					0.55239	*0.029632*	*0.11263*		*0.13437*

Country	Disturbance Variances				Final State Coefficients			Intervention Terms	Elasticity
	σ_{ω}^2	σ_{η}^2	σ_{ζ}^2	σ_{ι}^2	μ_t	β_t	ν_t		ε^s
Egypt	0	0	0	0.016945	19.298***	-0.022782***	0.13188	1993(O)	0.16435*
					0.41194	*0.0032775*	*0.0702*		*0.091624*
Greece	0	0	0.00027	0.012305	20.931***	-0.017517	-0.03239	1964(L), 1969(L), 1995(S)	-0.093930
					0.44613	*0.034391*	*0.10402*		*0.10856*
India	0	0	0	0.00881	21.280***	-0.0032508	0.05699	1989(L), 2003(L)	0.30683***
					0.30884	*0.0041044*	*0.08191*		*0.071439*
Iran	0.000113	0.014939	0	0.012556	18.090***	0.01677	-0.09537	1975(L), 1980(L)	0.30076**
					0.61423	*0.020306*	*0.10999*		*0.14744*
Mali	0.007497	0	0.000335	0.007087	19.102***	0.051272	-0.01646	1965(L), 1973(L), 1980(L), 2000(O)	0.20468
					0.5104	*0.036711*	*0.08157*		*0.12583*
Mexico	0.008118	0.046045	0	1.76E-05	14.291***	-0.065482*	-3.2E-05	1975(L), 1987(L), 1992(L), 1994(L)	1.0770***
					0.85686	*0.035901*	*0.00553*		*0.20731*
Myanmar	1.96E-06	0.026647	4.8E-08	1.07E-07	18.517***	0.015596	1.6E-07	1965(O), 1994(O), 1996(L)	0.043570
					0.56518	*0.025577*	*0.00033*		*0.13619*
Nigeria	0.004178	0.024573	0	0.091828	20.695***	0.031876	0.07677		-0.29796
					1.3219	*0.028359*	*0.38162*		*0.29887*
Pakistan	0.002959	0.014938	0	0.002399	21.877***	0.041559**	0.01989	1983(O)	0.11502
					0.52711	*0.019127*	*0.04967*		*0.12759*
Paraguay	0	0.042393	0	0.024811	15.457***	0.036011	0.08196	1971(O), 1997(O)	0.90744***
					0.94908	*0.032448*	*0.15437*		*0.22824*
Peru	2.98E-06	0.040338	0	0.006327	16.640***	-0.030577	0.01521	1983(O), 1998(O)	0.46453**
					0.76027	*0.031344*	*0.09758*		*0.18217*
Spain	0	0.061556	0.000227	2.53E-05	16.210***	0.013826	-3.1E-06	1995(O)	0.75426***
					0.84049	*0.062485*	*0.00714*		*0.20252*

Country	Disturbance Variances				Final State Coefficients			Intervention Terms	Elasticity
	σ^2_{ω}	σ^2_{η}	σ^2_{ζ}	σ^2_{ι}	μ_t	β_t	ν_t		ε^s
Sudan	0.017682	0.042759	0	0	17.177***	-0.012095	0	1991(L)	0.45718**
					0.91343	*0.032984*	*0*		*0.22182*
Syria	1.52E-06	0.017274	0	1.73E-05	19.392***	0.0088455	7.5E-05	1997(L)	0.25148**
					0.4493	*0.020688*	*0.00468*		*0.10826*
United Republic of Tanzania	0	0	0	0.082536	19.213***	0.0034206	0.55167	1998(O)	-0.11084
					0.77555	*0.0059155*	*0.12343*		*0.17329*
Togo	1.79E-06	0	0	0.029474	17.981***	0.057954***	-0.0429	1970(L), 1978(O), 1979(L), 1985(L)	0.18976
					0.54059	*0.0068187*	*0.07835*		*0.12727*
Turkey	0.000307	0.000193	2.82E-05	0.004064	20.787***	0.022945	0.00659	1971(L), 1975(L), 1978(L), 1995(L)	0.13611**
					0.27268	*0.01516*	*0.07247*		*0.064680*
United States of America	0.000928	1.45E-06	8.61E-05	0.021481	22.144***	0.022829	0.10993	1967(O), 1983(O)	0.16449
					0.50595	*0.022893*	*0.08997*		*0.12456*
Zimbabwe	0	0	0.011707	0.016208	17.090***	-0.021718	0.0118	1963(L), 1969(O), 1992(O), 1995(O)	0.47798***
					0.66702	*0.14298*	*0.13034*		*0.16063*

*Note: Statistical significance is indicated using * (10 percent), ** (5 percent) and *** (1 percent). Where relevant, standard errors are indicated in italics underneath the corresponding parameter estimate. Intervention terms are coded as Year(Type), where "type" refers to Outlier (impulse dummy), Level shift (step dummy) or Slope shift (staircase dummy), using the terminology of Koopman et al. (2000).*

Source: own calculations.

Table 3: Diagnostic tests – country equations

Country	Std. Err.	Rd2	Normality	Hetero-skedasticity	Q(10)
Argentina	0.29913	0.3731	0.65884	0.80198	3.067
Australia	0.29610	0.31798	0.073390	0.45841	11.085*
Benin	0.19625	0.59332	2.3717	1.0849	5.9434
Bolivia	0.25546	0.67870	1.5928	0.80030	9.5235
Burkina Faso	0.22961	0.36454	0.28275	1.2312	9.0044
Brazil	0.18560	0.36193	2.6571	1.6749	10.297
Cameroon	0.14551	0.53255	0.20059	0.26386	7.8942
Chad	0.15251	0.63852	2.9746	1.6612	5.2489
China	0.14049	0.35308	4.5727	0.79922	11.048*
Colombia	0.17895	0.57457	0.35906	1.9869	14.936**
Côte d'Ivoire	0.15898	0.44633	3.0849	0.99694	4.9829
Egypt	0.12512	0.44011	1.7493	3.1034**	9.0081
Greece	0.12678	0.31407	3.3487	1.0940	10.647*
India	0.089058	0.66909	3.2603	0.94890	6.9175
Iran	0.16717	0.31280	0.57216	1.3754	7.4172
Mali	0.14363	0.68433	0.12838	1.1933	5.7482
Mexico	0.22693	0.79611	0.031191	2.3043*	5.0891
Myanmar	0.15180	0.57220	0.80884	0.30145	15.029**
Nigeria	0.35012	0.095140	1.7068	0.25307	3.4509
Pakistan	0.14713	0.47955	0.64537	1.3717	8.1474
Paraguay	0.25986	0.58884	2.9705	2.4048*	8.3920
Peru	0.20674	0.50574	2.5832	5.2224***	11.508*
Spain	0.24363	0.40160	0.64180	2.3387*	4.4429
Sudan	0.25949	0.23874	0.15548	0.84524	5.8063
Syria	0.12556	0.22965	0.88451	1.4606	12.163*
United Republic of Tanzania	0.27588	0.42201	1.7636	3.3576**	13.340**
Togo	0.15856	0.73796	2.9598	0.78973	6.1029
Turkey	0.070634	0.57773	0.29669	0.49025	4.1713
United States of America	0.16666	0.49776	1.3033	0.50548	3.9688
Zimbabwe	0.20856	0.82942	0.69172	0.68774	5.8653

*Note: Statistical significance of test statistics is indicated using * (10 percent), ** (5 percent) and *** (1 percent). Std. Err. refers to the square root of the predication error variance. The goodness of fit statistic (Rd2) is as set out in Harvey (1989). Q(10) refers to the Box-Ljung test for up to 10th order serial correlation. Details of the normality (Bowman-Shenton à la Doornik-Hansen) and heteroskedasticity tests can be found in Koopman et al. (2000).*

Source: own calculations.

Table 4: Estimation results – aggregated regions

Region	Disturbance Variances σ^2_ω	σ^2_η	σ^2_ζ	σ^2_ι	Final State Coefficients μ_t	β_t	ν_t	Intervention Terms	Elasticity ε^s
Africa	0	0.00032503	0	0.0026403	21.662***	0.0017968	0.024363	1969(L), 1996(L), 2000(O)	0.088681*
					0.33373	*0.007523*	*0.27202*		*0.045747*
Caribbean	0	0.021756	0.00042344	0	14.085***	-0.039126	0	1964(L), 1968(L), 1995(L)	-0.049408
					0.52491	*0.057342*	*0*		*0.12648*
Central Africa	0.00086253	0.017365	5.3896E-07	0.00082	18.983***	0.0059991	0.012227	1982(L)	0.17912
					0.48954	*0.021006*	*0.028432*		*0.11832*
Central America	0.0018543	0.00043728	0	0.039579	15.026***	-0.075648***	-0.17146	1992(L), 1994(L)	0.95471***
					0.73446	*0.010021*	*0.13501*		*0.16672*
East Africa	0	0.0085738	0.0011419	0.0019707	19.233***	0.040631	0.031027	1968(O)	0.25680**
					0.41814	*0.062918*	*0.043181*		*0.10194*
East South East Asia	0.00022581	0.0094549	0	0.0026575	17.570***	0.012456	-0.022382	1969(L), 1977(O), 1979(L)	0.39961***
					0.42119	*0.015784*	*0.046381*		*0.10240*
EU15	4.0164E-06	0.00037517	0.00014542	0.0093023	20.094***	0.014565	-0.097754	1986(L)	0.18860*
					0.40395	*0.028166*	*0.1055*		*0.095639*
Far East	0.00015142	0.00017108	0.0012575	0.0034028	23.021***	0.10931**	0.044844	1984(O)	0.22144***
					0.29753	*0.051014*	*0.055701*		*0.072363*
Former USSR	0	6.30E-05	0.00010239	9.32E-05	15.016***	-0.033127*	-0.0069953	1970(L), 1974(L), 2003(L)	-0.062385***
					0.072698	*0.01659*	*0.008804*		*0.017799*
Latin America and Caribbean	0.00059937	0.01661	4.2533E-11	4.7079E-06	18.972***	-0.011256	4.9524E-05		0.72934***
					0.44917	*0.020002*	*0.0025821*		*0.10833*

Region	Disturbance Variances				Final State Coefficients			Intervention Terms	Elasticity
	σ_{ω}^{2}	σ_{η}^{2}	σ_{ζ}^{2}	σ_{ι}^{2}	μ_{t}	β_{t}	ν_{t}		ε^{s}
Near East	1.9715E-05	0.0030082	8.9072E-09	6.8737E-07	21.388***	0.0065913	9.684E-06	1975(L), 1995(L)	0.15334***
					0.19165	*0.0086965*	*0.000829*		*0.046190*
North East Asia	0.0019579	0.0013486	0.00054376	2.9819E-11	20.887***	0.0081379	-1.3618E-10		0.22236***
					0.2555	*0.038125*	*5.4607E-06*		*0.062557*
North/West Africa	0.00363	0.072324	0.00039123	0.00012056	15.461***	-0.07255	0.00012962	1992(O), 1993(O)	-0.19223
					0.97377	*0.074574*	*0.011822*		*0.23501*
South Asia	2.0527E-05	0.0093555	0	0.00045562	22.215***	0.027077*	0.0088422	1983(O)	0.23768***
					0.34344	*0.015021*	*0.022188*		*0.082762*
West Africa	0	0.009449	0	8.3588E-07	20.905***	0.059252***	-3.4012E-06	1968(O), 1969(O), 1970(O), 1974(O)	0.11438
					0.34261	*0.015077*	*0.0011922*		*0.082554*
World	0.0015745	0.00058183	0	0.00017449	23.934***	0.20804***	4.08E-05	1975(L), 1984(O), 2003(S)	0.18198***
					0.19342	*0.056531*	*0.013391*		*0.045477*

*Note: Statistical significance is indicated using * (10 percent), ** (5 percent) and *** (1 percent). Where relevant, standard errors are indicated in italics underneath the corresponding parameter estimates. Intervention terms are coded as Year(Type), where "type" refers to Outlier (impulse dummy), Level shift (step dummy) or Slope shift (staircase dummy), using the terminology of Koopman et al. (2000).*

Source: own calculations

Table 5: Diagnostic tests - aggregate region equations. (Source: own calculations.)

Region	SE	Rd2	Normality	Hetero skedasticity	Q(10)
Africa	0.050820	0.63781	0.36878	1.6978	6.0399
Caribbean	0.14670	0.64330	2.2109	0.99786	10.025
Central Africa	0.13827	0.20146	2.0677	1.1305	5.7955
Central America	0.19843	0.68498	5.8868*	1.5744	3.6821
East Africa	0.13721	0.21376	2.9382	1.8969	4.8120
East South East Asia	0.11525	0.64711	0.17257	0.36205	8.7384
EU 15	0.10978	0.18039	1.6860	0.88988	8.7461
Far East	0.094342	0.33398	2.7886	1.1136	4.0823
Former USSR	0.022537	0.60010	1.8111	2.0036	9.4469
Latin America/Caribbean	0.12896	0.54495	0.19674	2.4483*	10.019
Near East	0.052034	0.49042	0.66858	1.4560	13.588**
North East Asia	0.082173	0.12506	2.9920	0.52827	7.6718
North/West Africa	0.27510	0.54075	0.45891	1.2938	3.1238
South Asia	0.095858	0.47962	2.5701	0.99704	9.7374
West Africa	0.089156	0.56108	0.40755	1.7632	2.8141
World	0.051581	0.67797	0.21364	1.8556	7.1914

*Note: Statistical significance of test statistics is indicated using * (10 percent), ** (5 percent) and *** (1 percent). Std. Err. refers to the square root of the predication error variance. The goodness of fit statistic (Rd2) is as set out in Harvey (1989). Q(10) refers to the Box-Ljung test for up to 10^{th} order serial correlation. Details of the normality (Bowman-Shenton à la Doornik-Hansen) and heteroskedasticity tests can be found in Koopman et al. (2000).*

Source: own calculations

Table 6: Comparison with previous estimates of cotton supply elasticities

	Poonyth *et al.* (2004)	Coleman & Thigpen (1991)	Gilbert & Modena (2004)	Gillson *et al.* (2004)	Hugon (2005)	Sumner (2003)	Shepherd (2006)		
							Low	Mean	High
Countries									
Argentina	0.2	0.87-1.4				0.5	0.54	1.04	1.55
Australia	0.8			0.68		0.3	0.00	0.46	0.97
Benin	0.8		0.13	0.25	0.22-0.50		0.00	0.02	0.35
Bolivia	0.2						0.42	0.83	1.24
Burkina Faso	0.8		0.09	0.32-0.58	0.10-0.74		0.00	0.01	0.37
Brazil	1.2					0.4	0.31	0.63	0.95
Cameroon	0.2			0.35-0.47	-0.35-0.10		0.12	0.39	0.65
Chad	0.8		0.13	0.36	0.07-0.74		0.01	0.24	0.46
China	1.2	0.11		0.48		0.14	0.00	0.14	0.37
Colombia	0.8						0.23	0.54	0.85
Côte d'Ivoire	0.8			0.46-0.57	-0.83-0.16		0.00	0.00	0.15
Egypt	0.8			0.15-0.26			0.00	0.16	0.35
Greece							0.00	0.00	0.12
India	1.2	0.07-0.17		0.37		0.13	0.16	0.31	0.45
Iran	0.8						0.01	0.30	0.60
Mali	0.8		0.14	0.34-0.59	-0.36 to -0.03		0.00	0.20	0.46

	Poonyth *et al.* (2004)	Coleman & Thigpen (1991)	Gilbert & Modena (2004)	Gillson *et al.* (2004)	Hugon (2005)	Sumner (2003)	Shepherd (2006)		
							Low	Mean	High
Mexico	1	0.56				0.5	0.66	1.08	1.49
Myanmar	0.8						0.00	0.04	0.32
Nigeria	0.8			0.35			0.00	0.00	0.30
Pakistan	1.2	0.08		0.34		0.3	0.00	0.12	0.37
Paraguay	0.2						0.45	0.91	1.36
Peru	0.2						0.10	0.46	0.83
Spain	0.2						0.35	0.75	1.16
Sudan	0.2			0.4			0.01	0.46	0.90
Syria	0.8			0.26			0.03	0.25	0.47
United Republic of Tanzania	0.2			0.28-1.29			0.00	0.00	0.24
Togo	0.2		0.21	0.47-0.75	-0.26-0.04		0.00	0.19	0.44
Turkey	1.2	0.33		0.28		0.3	0.01	0.14	0.27
United States of America	0.8	0.27-0.95				0.361-0.424	0.00	0.16	0.41
Zimbabwe	0.8			0.33-0.95			0.16	0.48	0.80
Regions									
Africa				0.6		0.3	0.00	0.09	0.18
Caribbean							0.00	0.00	0.25
Central Africa		0.12					0.00	0.18	0.42
Central America							0.62	0.95	1.29

	Poonyth *et al.* (2004)	Coleman & Thigpen (1991)	Gilbert & Modena (2004)	Gillson *et al.* (2004)	Hugon (2005)	Sumner (2003)	Shepherd (2006)		
							Low	Mean	High
East Africa							0.05	0.26	0.46
East South East Asia						0.3	0.19	0.40	0.60
EU15						0.6	0.00	0.19	0.38
Far East							0.08	0.22	0.37
Former USSR						0.3	0.00	0.00	0.04
LatinAmerica/Caribbean						0.3	0.51	0.73	0.95
Near East							0.06	0.15	0.25
North East Asia							0.10	0.22	0.35
North West Africa							0.00	0.00	0.47
South Asia							0.07	0.24	0.40
West Africa							0.00	0.11	0.28
World							0.09	0.18	0.27

Note: Mean estimates are taken from coefficient estimates in Tables 2 and 4, replacing negative values with zero. High and low estimates are calculated as two standard error bounds above and below mean estimates, using the standard errors reported in italics in Tables 2 and 4.

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