Online Appendix

Strategic Uncertainty in Financial Markets: Evidence from a Consensus Pricing Service*

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Contents

1 Solution algorithm

Here, we show how to solve the consensus pricing problem using a solution algorithm developed in Nimark (2017). We adopt the following standard notation for higher-order expectations, defining recursively

$$\theta_t^{(0)} = \theta_t,$$
$$\theta_{i,t}^{(k+1)} = \mathbb{E}\left(\theta_t^{(k)} | \Omega_{i,t}\right) \quad \text{and} \quad \theta_t^{(k+1)} = \int_0^1 \theta_{i,t}^{(k+1)}\, di \text{ for all } k \geq 0.$$

We denote institution i's hierarchy of expectations up to order k by

$$\theta_{i,t}^{(1:k)} = \left(\theta_{i,t}^{(1)}, ..., \theta_{i,t}^{(k)}\right)^{\intercal}$$

and for the hierarchy of average expectations up to order k, including the fundamental value $\theta_t^{(0)}$ as first element,

$$\theta_t^{(0:k)} = \left(\theta_t^{(0)}, \theta_t^{(1)}, ..., \theta_t^{(k)}\right)^{\intercal}.$$

The solution procedure proceeds recursively. It starts with a fixed order of expectations $k \geq 0$ and postulates that the dynamics of average expectations $\theta_t^{(0:k)}$ are given by the VAR(1)

$$\theta_t^{(0:k)} = M_k\, \theta_{t-1}^{(0:k)} + N_k\, w_t, \tag{1}$$

with $w_t = (u_t, \varepsilon_{t-1})^{\intercal}$ and $\theta_t^{(n)} = \theta_t^{(k)}$ for all $n \geq k$.

Institution i's signal can be expressed in terms of current and past average expectations, $\theta_t^{(0:k)}$ and $\theta_{t-1}^{(0:k)}$, and the period t shocks w_t and $\eta_{i,t}$. The private signal can be written as

$$s_{i,t} = e_1^{\intercal}\, \theta_t^{(0:k)} + \sigma_\eta\, \eta_{i,t},$$

where e_j denotes a column vector of conformable length with a 1 in position j, all other elements being 0. Similarly, we can express the consensus price p_t as

$$p_t = \theta_t^{(1)} + \sigma_\varepsilon\, \varepsilon_t = e_2^{\intercal}\, \theta_t^{(0:k)} + \sigma_\varepsilon\, \varepsilon_t.$$

Denote the vector of signals by $z_{i,t} = (s_{i,t}, p_{t-1})^{\intercal}$. We can now express the signals in terms of current and past average expectations and shocks,

$$z_{i,t} = D_{k,1}\, \theta_t^{(0:k)} + D_{k,2}\, \theta_{t-1}^{(0:k)} + R_w\, w_t + R_\eta\, \eta_{i,t}, \tag{2}$$

where

$$D_{k,1} = \begin{bmatrix} e_1^{\intercal} \\ 0_{k+1}^{\intercal} \end{bmatrix}, \quad D_{k,2} = \begin{bmatrix} 0_{k+1}^{\intercal} \\ e_2^{\intercal} \end{bmatrix}, \quad R_\eta = \begin{bmatrix} \sigma_\eta \\ 0 \end{bmatrix} \text{ and } R_w = \begin{bmatrix} 0 & 0 \\ 0 & \sigma_\varepsilon \end{bmatrix}.$$

We thus obtain a state space representation of the system from the perspective of institution i. Equation (1) describes the dynamics of the latent state variable $\theta_t^{(0:k)}$; Equation (2) is the observation equation that provides the link between the state and i's signals. Using a Kalman filter that allows for lagged state variables (Nimark 2015) allows us to express institution i's expectations conditional on the information contained in $\Omega_{i,t}$ as

$$\theta_{i,t}^{(1:k+1)} = M_k\, \theta_{i,t-1}^{(1:k+1)} + K_k \left[z_{i,t} - D_{1,k}\, M_k\, \theta_{i,t-1}^{(1:k+1)} - D_{2,k}\, \theta_{i,t-1}^{(1:k+1)} \right], \tag{3}$$

where K_k is the (stationary) Kalman gain. Substituting out the signal vector in terms of state variables and shocks, this can equivalently be written as

$$\begin{aligned} \theta_{i,t}^{(1:k+1)} = {} & [M_k - K_k(D_{1,k}M_k + D_{2,k})]\, \theta_{i,t-1}^{(1:k+1)} \\ & + K_k(D_{1,k}M_k + D_{2,k})\theta_{t-1}^{(0:k)} + K_k(D_{1,k}N_k + R_w)w_t + K_k R_\eta\, \eta_{i,t}. \end{aligned}$$

Averaging this expression across all submitters, assuming that by a law of large numbers $\int_0^1 \eta_{i,t}\, di = 0$, average expectations are then given by

$$\begin{aligned} \theta_{t}^{(1:k+1)} = {} & [M_k - K_k(D_{1,k}M_k + D_{2,k})]\, \theta_{t-1}^{(1:k+1)} \\ & + K_k(D_{1,k}M_k + D_{2,k})\theta_{t-1}^{(0:k)} + K_k(D_{1,k}N_k + R_w)w_t. \end{aligned}$$

Combined with the fact that $\theta_t^{(0)} = \rho\, \theta_{t-1}^{(0)} + \sigma_u\, u_t$, we now obtain a new law of motion for the state,

$$\theta_t^{(0:k+1)} = M_{k+1}\, \theta_{t-1}^{(0:k+1)} + N_{k+1}\, w_t,$$

with

$$M_{k+1} = \begin{bmatrix} \rho\, e_1^\intercal & 0 \\ K_k(D_{1,k}M_k + D_{2,k}) & 0_{k\times 1} \end{bmatrix} + \begin{bmatrix} 0 & 0_{1\times k} \\ 0_{k\times 1} & M_k - K_k(D_{1,k}M_k + D_{2,k}) \end{bmatrix} \tag{4}$$

and

$$N_{k+1} = \begin{bmatrix} \sigma_u\, e_1^\intercal \\ K_k(D_{1,k}N_k + R_w) \end{bmatrix}. \tag{5}$$

Note, however, that now the state space has increased by one dimension from $k+1$ to $k+2$. This is a consequence of the well-known infinite regress problem when filtering endogenous signals. When filtering signals based on average expectations of order k, institutions have to form beliefs about average expectations of order k. But this implies that equilibrium dynamics are influenced by average expectations of order $k+1$, and so on for all orders $k \geq 0$.

In practice, the solution algorithm works as follows. We initialize the iteration at $k = 0$ with $M_0 = \rho$ and $N_0 = \sigma_u$, which implies that $\theta_t^{(1)} = \theta_t^{(0)}$ for all t. Consequently, the consensus price of the first iteration is given by[1]

$$p_t^{[1]} = \theta_t^{(0)} + \sigma_\varepsilon\, \varepsilon_t.$$

This yields a Kalman gain K_0 (here a two-dimensional vector) which can then be used to obtain M_1 and N_1 via equations (4) and (5) and so on until either convergence of the process $p_t^{[n]}$ has been achieved according to a prespecified convergence criteria after n steps or a upper bound on steps has been reached. The highest-order belief that is not trivially defined by lower-order beliefs is then of order n.

2 Proof of identification

Strategy of proof The proof of identification proceeds in two steps. First, we establish identification for the model under the assumption that submitting institutions take the consensus price to be an exogenous signal of the current state, i.e. $p_t = \theta_t + \varepsilon_t$ where $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$. This is the model of the first step in Nimark (2017)'s solution algorithm. Second, once we have established identification of the first-step model, we proceed by induction. In particular, we argue that if the model is identified at step n of the algorithm, it is also identified at step $n+1$. This then establishes identification of the model at all steps of the algorithm.

A. Identification with exogenous consensus price signal

If submitters assume that the consensus price is an exogenous signal of the (past) state, then individual submitters' first-order beliefs are updated according to

$$\theta_{i,t} = \rho\, \theta_{i,t-1} + (k_{11}\ k_{12}) \begin{pmatrix} \theta_t + \eta_{i,t} - \rho\, \theta_{i,t-1} \\ \theta_{t-1} + \varepsilon_{t-1} - \theta_{i,t-1} \end{pmatrix},$$

where $\eta_{i,t} \sim N(0, \sigma_\eta^2)$. We can write this as

$$\theta_{i,t} = (1-k)\rho\, \theta_{i,t-1} + k\, \rho\, \theta_{t-1} + k_{11}\, u_t + k_{12}\, \varepsilon_{t-1} + k_{11}\, \eta_{i,t}, \tag{6}$$

where the Kalman gains k_{11} and k_{12} are given by

$$k_{11} = \frac{\zeta + \rho^2 k}{\zeta + \rho^2 + \psi/(1-\psi)} \ \text{ and } \ k_{12} = \rho(k - k_{11}) \ \text{ with}$$

$$k = \frac{1}{2} + \frac{1}{2\rho^2}\left\{ \left[(1-\rho)^2 + \xi\right]^{\frac{1}{2}} \left[(1+\rho)^2 + \xi\right]^{\frac{1}{2}} - (1+\xi) \right\},$$

$$\xi = \frac{\zeta}{\psi} \ \ , \ \ \psi = \frac{\sigma_\eta^2}{\sigma_\varepsilon^2 + \sigma_\eta^2} \ \text{ and } \ \zeta = \frac{\sigma_u^2}{\sigma_\varepsilon^2}.$$

[1] Superscripts in square brackets denote iterations of the algorithm.

The average first-order belief is then

$$\bar{\theta}_t = (1-k)\rho\,\bar{\theta}_{t-1} + k\,\rho\,\theta_{t-1} + k_{11}\,u_t + k_{12}\,\varepsilon_{t-1},$$

with corresponding (step 2) consensus price process

$$p_t = \bar{\theta}_t + \varepsilon_t.$$

This implies the following dynamics for the consensus price,

$$p_t = (1-k)\rho\,p_{t-1} + k\,\rho\,\theta_{t-1} + k_{11}\,u_t + (k_{12} - (1-k)\rho)\varepsilon_{t-1} + \varepsilon_t. \tag{7}$$

Observed data We assume that our observed data consists of a panel of individual first-order beliefs for S submitting institutions $\{\{\theta_{i,t}\}_{i=1}^{S}\}_{t=1}^{T}$ that evolve according to (6), and the corresponding time-series of consensus prices $\{p_t\}_{t=1}^{T}$ is generated by the process specified in (7).

We now show how the distribution of the above data identifies the model parameters of interest, namely $\{\rho, \sigma_\varepsilon^2, \sigma_\eta^2, \sigma_u^2\}$.

1. Deviations of the consensus price from average expectations identify σ_ε^2.
We obtain estimates for the error ε_t from the difference between the current consensus price and the current mean across submissions,

$$\varepsilon_t = p_t - \bar{\theta}_t.$$

We can thus identify σ_ε^2 from the time-series variance of the estimated errors.

2. Individual deviations from average expectations identify $(1-k)\rho$.
Individual deviations from the consensus, $\hat{\theta}_{i,t} = \theta_{i,t} - \bar{\theta}_t$ are given by

$$\hat{\theta}_{i,t} = (1-k)\rho\,\hat{\theta}_{i,t-1} + k_{11}\,\eta_{i,t}.$$

Individual deviations follow an AR(1) process. Deviations from consensus mean-revert more quickly if submitters put less weight on past information (higher k), or if the fundamental value process is less persistent (low ρ). We can therefore identify $(1-k)\rho$ from the auto-covariances of individual deviations from the current mean submission.

3. Persistence in consensus price updates identifies ρ and hence k via $(1-k)\rho$.
Having identified $(1-k)\rho$ we can obtain $\omega_t = p_t - (1-k)\rho\,p_{t-1}$ from our data, where

$$\omega_t = k_{11}\,u_t + k\,\rho\left(\frac{u_{t-1}}{1-\rho L}\right) + (k_{12} - (1-k)\rho)\varepsilon_{t-1} + \varepsilon_t.$$

ω_t is a noisy measure of the news about the fundamental value submitters receive in period t. By subtracting $(1-k)\rho\, p_{t-1}$ from p_t it "eliminates" their prior beliefs. For sufficiently long lags, ω_t's auto-correlation exclusively comes from its dependence on the fundamental process and not the aggregate noise, ε_t. Its auto-covariances thus allow us to identify the persistence in the process of θ_t. In particular, we can see that the auto-covariances of ω_t have to satisfy

$$Cov(\omega_t, \omega_{t-3}) = \rho\, Cov(\omega_t, \omega_{t-2}).$$

The ratio of these auto-covariances thus identify ρ,

$$\rho = Cov(\omega_t, \omega_{t-3})/Cov(\omega_t, \omega_{t-2}),$$

which together with $(1-k)\rho$ then allow us to identify $1-k$, i.e. the persistence in individual expectations due to informational frictions.

4. The weight submitters put on the consensus price when updating expectations identifies σ_η^2 and hence σ_u^2 via k.
k determines how much weight submitters put on new information as opposed to their priors. It is given by

$$k = \frac{1}{2} + \frac{1}{2\rho^2}\left\{\left[(1-\rho)^2+\xi\right]^{\frac{1}{2}}\left[(1+\rho)^2+\xi\right]^{\frac{1}{2}} - (1+\xi)\right\},$$

$$\text{where } \xi = \frac{\zeta}{\psi} \text{ with } \psi = \frac{\sigma_\eta^2}{\sigma_\varepsilon^2+\sigma_\eta^2} \text{ and } \zeta = \frac{\sigma_u^2}{\sigma_\varepsilon^2}.$$

It is a function of ξ, which is a ratio of the variance of the shocks to the fundamental value to the variance of the signal noises and can thus be seen as a measure of the signal to noise ratio. k is monotonically increasing in ξ; a higher signal to noise ratio implies a higher weight on current signals. Hence, having already identified k, we can also identify ξ.

In turn, the weights submitters put on the private signal and the consensus price can be expressed in terms of k, ξ, and ψ, namely

$$k_{11} = \frac{\xi\,\psi + \rho^2\,k}{\xi\,\psi + \rho^2 + \psi/(1-\psi)} \text{ and } k_{12} = \rho(k - k_{11}).$$

It can be shown that, for a given k, the weight on the private signal, k_{11}, is monotonically decreasing and the weight on the consensus price, k_{12}, monotonically increasing in ψ for $\psi \in (0,1)$; a relatively more noisy private signal will lead submitters to shift weight from the private signal to the consensus price (given k). As we have already identified k and ξ, knowing either k_{11} or k_{12} will allow us to identify ψ. Given ψ we can then back out σ_η^2 and ζ, which yields σ_u^2.

We now proceed to show identification of k_{12}, which by the previous argument establishes identification of the model. To do so, we return to the individual expectation updating equation,

$$\theta_{i,t} = (1-k)\rho\,\theta_{i,t-1} + k_{11}\,\rho\,\theta_{t-1} + k_{12}\,p_{t-1} + k_{11}\,\eta_{i,t} + k_{11}\,u_t.$$

We also have

$$\theta_{i,t-1} = (1-k)\rho\,\theta_{i,t-2} + k_{11}\,\theta_{t-1} + k_{12}\,p_{t-2} + k_{11}\,\eta_{i,t-1}.$$

Multiplying the latter expression by ρ and subtracting from the former eliminates the unobservable θ_{t-1}. We obtain an expression in terms of observables and shocks,

$$\theta_{i,t} - \rho\,\theta_{i,t-1} = (1-k)\rho(\theta_{i,t-1} - \rho\,\theta_{i,t-2}) + k_{12}\,(p_{t-1} - \rho\,p_{t-2}) + k_{11}(\eta_{i,t} - \rho\,\eta_{i,t-1}) + k_{11}\,u_t.$$

Note that we have already identified $(1-k)\rho$. Define

$$y_{i,t} = \theta_{i,t} - \rho\,\theta_{i,t-1} - (1-k)\rho(\theta_{i,t-1} - \rho\,\theta_{i,t-2}).$$

We can then identify the coefficient k_{12} from the covariance of $y_{i,t}$ and $p_{t-1} - \rho\,p_{t-2}$ noting that

$$y_{i,t} = k_{12}\,(p_{t-1} - \rho\,p_{t-2}) + k_{11}(\eta_{i,t} - \rho\,\eta_{i,t-1}) + k_{11}\,u_t.$$

This is possible as p_{t-1} is a signal based on period $t-1$ information. It is not correlated with the shock u_t. Furthermore, the idiosyncratic noise terms $\eta_{i,t}$ and $\eta_{i,t-1}$ are uncorrelated with the consensus price process by construction.

B. Establishing identification by induction

Suppose we have established identification of the model parameters by our observed data for step n of the algorithm. That is, any two distinct sets of parameters ϕ_1 and ϕ_2 imply distinct distributions of the observable data. In particular, the step n consensus price process that submitters will assume in step $n+1$ differs across the two parameter sets. This necessarily implies that the distribution of individual expectations will differ across the two parameter sets in step $n+1$. This then establishes identification of the model at step $n+1$ of the algorithm.

3 The value of information in OTC markets

This is a simple one-period model to illustrate the value of the consensus price information for dealers in the OTC options market. It shows that dealers that use an interdealer market to share risk are naturally concerned about both fundamental asset values and other dealers' valuation. A dealer is willing to pay for information that reduces its uncertainty in any of these two dimensions.

The model

Before entering the market, every dealer $i \in [0,1]$ observes a private signal about the fundamental value of an option, given by the random variable θ. She can also pay to receive a public signal about that value. For now, the exact form of these signals is not important. The game proceeds in three steps:

1. Dealer $i \in [0,1]$ decides whether to buy the public signal at cost f.
2. After observing signal(s), the dealer enters the market and is matched with a client. A client is a buyer or seller of one option contract with equal probability. The dealer can credibly communicate her valuation of the option to the client. The client is willing to pay (receive) at most Δ in excess of (below) the dealer's valuation.
3. After buying or selling the option from the client, dealer i enters the interdealer market. She is matched with a dealer with opposite option inventory with probability $0 \leq \gamma \leq 1$. If matched, dealers trade at the average expectation of fundamental values among active dealers denoted by $\bar{\theta}$.[2]
4. If a dealer has not been matched in the interdealer market (probability $1-\gamma$) she hedges the option herself. At expiry, she receives the fundamental value θ but hedging physically creates a cost of $c > 0$.

Pricing after entry

Suppose dealer i is matched with a client that wants to buy. The dealer charges a price a_i to the client. If the dealer is matched in the interdealer market, her profit is $a_i - \bar{\theta}$. Otherwise her profit is $a_i - \theta - c$. We assume that the dealer minimizes a loss function that is quadratic in losses.[3] The pricing problem is then

$$\mathcal{L}_i^s = \min_a \mathbb{E}_i \left\{ \gamma (a - \bar{\theta} - \pi)^2 + (1-\gamma)(a - \theta - c - \pi)^2 \right\},$$

where the expectation is taken over dealer i's information set when she is interacting with the client, that is after entry and having observed signals, but before entering the interdealer market. The first-order condition for a yields the optimal price,

$$a_i^* = \pi + \gamma \, \mathbb{E}_i \, \bar{\theta} + (1-\gamma) \mathbb{E}_i \, (\theta + c).$$

We assume that dealer i can credibly communicate the "fair value" of the option, namely $\gamma \, \mathbb{E}_i \, \bar{\theta} + (1-\gamma)\mathbb{E}_i \, (\theta + c)$, to her client. For the client to buy, we further assume that the markup in the optimal price is smaller than the client's maximal

[2]We do not explicitly model the trading mechanism that would yield this as a market-clearing price of interdealer market.

[3]This captures the idea that dealers' institutions prefer smooth profits with target level π.

willingness to pay, that is $\pi \leq \Delta$.

Substituting a_i^* back into the loss function we find

$$\mathcal{L}_i^s = \gamma\,\mathbb{E}_i\left(\bar{\theta} - \bar{\theta}_i\right)^2 + (1-\gamma)\,\mathbb{E}_i\left(\theta - \theta_i\right)^2 + \gamma(1-\gamma)(\delta_i + c)^2,$$

where $\delta_i = \theta_i - \bar{\theta}_i$.

The case for a dealer buying from a client at price b is symmetric with loss function

$$\mathcal{L}_i^b = \min_b \mathbb{E}_i\left\{\gamma(\bar{\theta} - b - \pi)^2 + (1-\gamma)(\theta - b - c - \pi)^2\right\}.$$

It yields a nearly identical loss function to the case of buying from a client, namely,

$$\mathcal{L}_i^b = \gamma\,\mathbb{E}_i\left(\bar{\theta} - \bar{\theta}_i\right)^2 + (1-\gamma)\,\mathbb{E}_i\left(\theta - \theta_i\right)^2 + \gamma(1-\gamma)(\delta_i - c)^2.$$

Participation decision

The ex-ante expected loss of dealer i with signals $\mathbf{s}_i$ is

$$\begin{aligned} -\mathbb{E}\left(\frac{1}{2}\mathcal{L}_i^s + \frac{1}{2}\mathcal{L}_i^b \mid \mathbf{s}_i\right) = {} & -\gamma\,\mathrm{Var}(\bar{\theta} \mid \mathbf{s}_i) - (1-\gamma)\mathrm{Var}(\theta \mid \mathbf{s}_i) \\ & - \gamma(1-\gamma)\,\mathbb{E}(\,\delta_i^2 \mid \mathbf{s}_i) - \gamma(1-\gamma)\,c^2. \end{aligned}$$

The dealer buys the public signal if the reduction in expected loss exceeds the price of the signal, which is f.

The public signal is valued as it allows for better pricing decisions. Its ability to reduce strategic uncertainty is valued as it helps to predict prices in the interdealer market.

4 Demand-based option pricing

Here, we show how the assumed AR(1) process for the fundamental value of the option (expressed in terms of the logarithm of its implied volatility), i.e.

$$\theta_t = \rho\,\theta_{t-1} + \sigma_u\,u_t \;\text{ with }\; u_t \sim N(0,1),$$

can be obtained within the framework of demand-based option pricing developed in Gârleanu et al. (2009). The framework shows how demand pressures can influence option prices when option dealers are risk averse and asset markets are not frictionless. We refer to the paper for details.

The price of the asset that underlies the options contract follows a geometric Brownian motion, i.e.

$$dS_t = \mu\, S_t\, dt + \sigma\, S_t\, dW_t.$$

In the absence of demand pressure, each option has a constant Black-Scholes implied volatility of σ, that is the volatility surface is flat in all periods.

We assume that the only source of friction is the inability to hedge options continuously. For this case, Gârleanu et al. (2009) show that the Black-Scholes IV for option i changes with a shift in demand for option j according to

$$\frac{\partial \sigma_t^i}{\partial d_t^j} = \frac{\gamma\, r\, Var_t\left((\Delta S)^2\right)}{4}\, \frac{f_{SS}^i}{\nu^i}\, f_{SS}^j + o\left(\Delta_t^2\right)$$

where f^i is the Black-Scholes (BS) price of option i, f_{SS}^i is option i's BS gamma and ν^i is option i's BS vega, r is the risk-free rate, and γ is the coefficient of relative risk aversion of the risk-averse dealers with CRRA utility. Δ_t is the time interval between two re-hedging opportunities, the only source of friction in this model.

As the price of the underlying, S, follows Brownian motion we have

$$\Delta S = S_{t+\Delta_t} - S_t \approx \mu\, S_t\, \Delta_t + \sigma \sqrt{\Delta_t}\, S_t\, \varepsilon,$$

where $\varepsilon \sim N(0,1)$. It follows that

$$Var_t\left((\Delta S)^2\right) = Var_t\left(\sigma^2\, \Delta_t\, S_t^2\, \varepsilon^2 + 2\mu\, \sigma\, S_t^2\, \Delta_t^{3/2}\, \varepsilon\right) = 2\sigma^4\, S_t^4\, \Delta_t^2 + o\left(\Delta_t^2\right),$$

BS gamma of option i is

$$f_{SS}^i = \frac{\phi(d_1)}{\sigma\, S_t \sqrt{\tau}},$$

and BS vega of option i is

$$\nu^i = S_t \sqrt{\tau}\, \phi(d_1),$$

where

$$d_1 = \frac{\log(S/K) + (r + \frac{1}{2}\sigma^2)\tau}{\sigma\sqrt{\tau}}.$$

Thus, using the above result from Gârleanu et al. (2009), the change in the IV of option i induced by a marginal change in demand for this option is

$$\frac{\partial \sigma_t^i}{\partial d_t^i} = \frac{1}{2}\, \gamma\, r \left(\frac{\sigma\, \Delta_t}{\sqrt{\tau}}\right)^2 \frac{\phi(d_1)}{\sqrt{\tau}}\, S_t + o\left(\Delta_t^2\right).$$

Here, d_t^i is client demand for option i in units of options. We define the corresponding dollar demand for option i as

$$\hat{d}_t^i = d_t\, p_t^i = \kappa^i\, S_t\, d_t,$$

where κ^i is a function of moneyness K/S, σ, and τ only. It follows that

$$\frac{\partial \sigma_t^i}{\partial \hat{d}_t^i} \approx \frac{1}{2}\gamma\, r \left(\frac{\sigma\,\Delta_t}{\sqrt{\tau}}\right)^2 \frac{\phi(d_1)}{\kappa^i\,\sqrt{\tau}}.$$

Also note that

$$\frac{\partial \log\, \sigma_t^i}{\partial \hat{d}_t^i} = \frac{\partial \sigma_t^i}{\partial \hat{d}_t^i}\frac{1}{\sigma_t^i},$$

which, for σ_t^i close to its long-run mean σ^i, implies that

$$\frac{\partial \log\, \sigma_t^i}{\partial \hat{d}_t^i} \approx \frac{1}{2}\gamma\, r \left(\frac{\sigma\,\Delta_t}{\sqrt{\tau}}\right)^2 \frac{\phi(d_1)}{\kappa^i\,\sigma^i\sqrt{\tau}} \equiv \lambda^i.$$

We assume that the impact of dollar demand for an option $j \neq i$ on the IV of option i is negligible. Let $\bar{d}^i$ denote the mean of $\hat{d}_t^i$. Then for σ_t^i close to σ^i and $\hat{d}_t^i$ close to $\bar{d}^i$ we approximately have

$$\log \sigma_t^i = \log \sigma^i + \lambda^i \left(\hat{d}_t^i - \bar{d}^i\right) = \left(\log \sigma^i - \lambda^i \bar{d}^i\right) + \lambda^i\, \hat{d}_t^i.$$

Now suppose dollar demand for option i follows an AR1 process,

$$\hat{d}_t^i = (1-\rho^i)\bar{d}^i + \rho^i\, \hat{d}_{t-1}^i + e_t^i.$$

Substituting this process into the previous expression for $\log \sigma_t^i$ yields an AR1 process for log IV that is driven by the demand shock e_t^i,

$$\log \sigma_t^i = (1-\rho^i) \log \sigma^i + \rho^i\, \log \sigma_{t-1}^i + \lambda^i\, e_t^i.$$

5 IHS Markit's Totem submission process

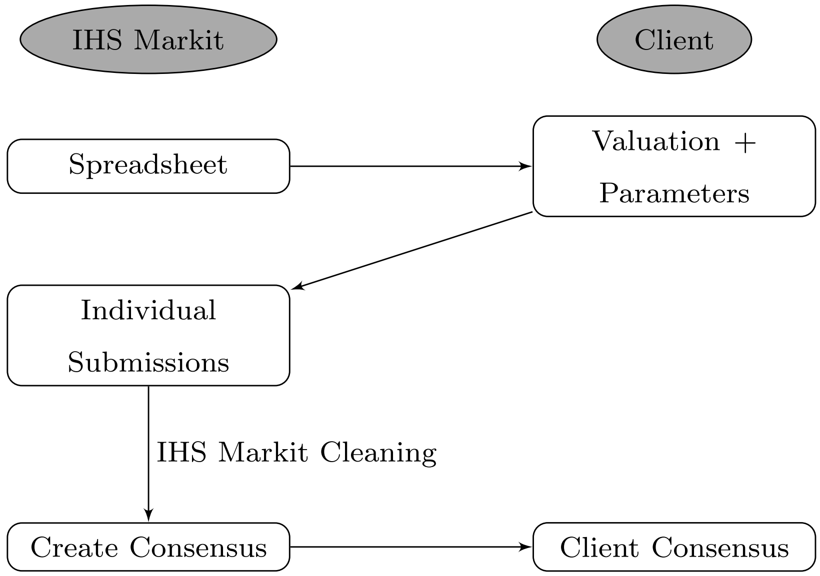

Figure 1: Diagram – Submission process

Figure 1 depicts a diagram of the submission process to IHS Markit's Totem service for plain vanilla index options.[4] On the last trading day of the month, Totem issues a spreadsheet to the n dealers that participate in the service. Dealers have to submit estimates for the mid price, defined as the average of bid price and offer price, of a range of put options with a moneyness between 80 and 100 and a range of call options with a moneyness ranging from 100 to 120 with a time-to-expiration of 6 months. Dealers that want to submit prices for different contracts are required to submit to all the available strike price and time-to-expiration combinations that lie in between the required contracts and the additionally demanded contracts.

We denote submitter i's estimate for the mid-price of an out-of-the-money (OTM) put with moneyness K, defined as the strike price of the option divided by the spot price of the underlying asset times 100, and time-to-expiration T (in days) by $P^i(p, K, T)$ and the mid-price estimate for an OTM call option with the same moneyness and

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time-to-expiration by $P^i(c, K, T)$. Submitter i also needs to submit the following input in addition to the mid-price estimate:

- the discount factor $\beta^i(T)$,
- the reference level $R^i(T)$, that is the price of a futures contract with maturity date closest to the valuation date,
- and the implied spot level $S^i(K, T)$, that is the implied level of the underlying index of the futures contract.

Submitters are provided with precise instructions for the timing of the valuation and the reference level that is to be used. To address any issues which might still arise with respect to valuation timing and the effect it could have on the comparability of prices across submitters, the submitted prices are aligned according to a predefined mechanism. The average consensus-implied spot from the at-the-money 6-month option, that is $\bar{S}(100, 6)$, is used for all other combinations of K and T. The submitted prices are restated in terms of $\bar{S}(K, T)$, giving: $\widehat{p}^i(\{c, p\}, K, T) = {}^{P^i(\{c,p\},K,T)}/_{\bar{S}(K,T)}$.

Given the submitted quantities, a Totem analyst calculates various implied quantities to validate the individual submissions. Put-call parity for ATM options is used to retrieve the relative forward, i.e.,

$$f^i(K, T) = \frac{\widehat{p}^i(c, K, T) - \widehat{p}^i(p, K, T)}{\beta^i(T)} + 1$$

The above inputs are then used in the Black-Scholes model,

$$\widehat{p}^i(c, K, T) = \beta^i(T)\left[f^i(K, T)\, N(d_{1,i}) - KN(d_{2,i})\right]$$

$$d_{1,i} = \frac{\ln\left(\frac{f^i}{K}\right) + \left(\frac{(\sigma^i)^2}{2}\right)T^a}{\sigma^i\sqrt{T^a}} \quad \text{, where} \quad T^a = \frac{\mathrm{T}}{365.25}$$

$$d_{2,i} = d_{1,i} - \sigma^i\sqrt{T^a}$$

to back-out σ^i in the above expression, which yields the implied volatility (IV) corresponding to submitter i's price submission for the given contract. We denote this IV by $\sigma_i(K, T)$. Here $N()$ is the cdf of the standard normal distribution.

When reviewing submissions, Totem analysts compare these IVs against other submitted prices and market conditions. They take the following points into consideration:

- the number of contributors,
- market activity & news,
- market conventions,
- the distribution and spread of contributed data,

- and, in a "one way market," they check if the concept of a mid-market price is clearly understood.

In addition to these criteria, analysts also visually inspect the ATM implied volatility term structure and the shape of the implied volatility curve for a given term, also referred to as the skew or the smile. After the vetting process, the analyst proceeds to the aggregation of the individual submissions into the consensus data.

Submitters' implied volatilities $\sigma_i(K,T)$ are aggregated into the consensus IV,

$$\bar{\sigma}\left(K,T\right) = \frac{1}{n(K,T)} \sum_{i=1}^{n(K,T)} \sigma_i\left(K,T\right).$$

Here $n(K,T)$ is the number of IVs used to calculate the consensus IV. Given more than 6 non-rejected IVs are available, the highest and lowest IV are excluded in the calculation to obtain a robust consensus IV. The same process takes place for the submitted prices to calculate a consensus price.

Submitters whose pricing information has been accepted by the Totem service receive the consensus information within 5 hours of the submission deadline. The consensus data include the average, standard deviation, skewness, and kurtosis of the distribution of accepted prices and implied volatilities. They also include the number of submitters to the consensus data.

6 Covariance matrices for counterfactuals

Consensus price perfectly reveals past state

If the consensus price perfectly aggregates dispersed information, we have

$$p_t = \theta_t.$$

In this case all submitters start period t with a common prior about θ_t, namely $\rho\,\theta_{t-1}$, and there is no higher-order uncertainty before receiving new signals. This is because every submitter knows that every submitter knows (and so on ...) that the average expected value of θ_t before receiving period t signals is $\rho\,\theta_{t-1}$.

Submitter i's expectations about the fundamental given signal $s_{i,t} = \theta_t + \eta_{i,t}$ can be obtained by the standard updating formula as state θ_t and signal $s_{i,t}$ given θ_{t-1} are jointly normally distributed:

$$\mathbb{E}_{i,t}\left(\theta_t\right) = \theta_{i,t} = \rho\,\theta_{t-1} + k_1\left(s_{i,t} - \rho\,\theta_{t-1}\right) = \rho\,\theta_{t-1} + k_1(u_t + \eta_{i,t})\,,$$

where k_1 is the Kalman gain

$$k_1 = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_\eta^2}.$$

It follows that the average expectation is

$$\bar{\theta}_t = \rho\,\theta_{t-1} + k_1\,u_t.$$

Now define the random vector

$$X_t = \left[\theta_t - \rho\,\theta_{t-1}\,,\,\bar{\theta}_t - \rho\,\theta_{t-1}\right] = \left[u_t\,,\,k_1\,u_t\right]$$

and

$$y_{i,t} = s_{i,t} - \rho\,\theta_{t-1} = u_t + \eta_{i,t}.$$

X_t and $y_{i,t}$ are jointly normally distributed. Thus, the covariance of X_t given $y_{i,t}$ is

$$Var\left(X_t|y_{i,t}\right) = \Sigma_{xx} - \Sigma_{xy}\left(\sigma_y^2\right)^{-1}\Sigma_{xy}^{\mathsf{T}},$$

where Σ_{xx} is the variance of X_t and Σ_{xy} is the covariance of X_t and $y_{i,t}$, namely,

$$\Sigma_{xx} = \begin{bmatrix} \sigma_u^2 & k_1\sigma_u^2 \\ k_1\sigma_u^2 & k_1^2\,\sigma_u^2, \end{bmatrix}\ ,\ \Sigma_{xy} = \left[\sigma_u^2\ ,\ k_1\,\sigma_u^2\right]^{\mathsf{T}}.$$

As $\rho\,\theta_{t-1}$ is known in t, $Var((\theta_t,\bar{\theta}_t)^{\mathsf{T}}|\Omega_{i,t}) = Var((\theta_t,\bar{\theta}_t)^{\mathsf{T}}|\theta_{t-1},y_{i,t}) = Var\left(X_t|y_{i,t}\right)$. It follows that

$$Var((\theta_t,\bar{\theta}_t)^{\mathsf{T}}|\Omega_{i,t}) = \begin{bmatrix} \frac{\sigma_u^2\,\sigma_\eta^2}{\sigma_u^2+\sigma_\eta^2} & \frac{\sigma_u^4\sigma_\eta^2}{(\sigma_u^2+\sigma_\eta^2)^2} \\ \frac{\sigma_u^4\sigma_\eta^2}{(\sigma_u^2+\sigma_\eta^2)^2} & \frac{\sigma_u^6\sigma_\eta^2}{(\sigma_u^2+\sigma_\eta^2)^3} \end{bmatrix}.$$

No consensus price feedback

Without consensus price feedback, the stationary expectation dynamics of submitter i are given by

$$\theta_{i,t} = \rho\,\theta_{i,t-1} + k_1\left(s_{i,t} - \rho\,\theta_{i,t-1}\right),$$

where k_1 is the stationary Kalman gain. k_1 is the solution to the system of two equations in two unknowns, k_1 and σ^2,

$$k_1 = \frac{\sigma^2}{\sigma^2 + \sigma_\eta^2}\ ,\ \sigma^2 = \rho^2(1-k_1)\sigma^2 + \sigma_u^2.$$

The average stationary expectation then evolves according to

$$\bar{\theta}_t = (1-k_1)\rho\,\bar{\theta}_{t-1} + k_1\rho\,\theta_{t-1} + k_1\,u_t.$$

We can write the dynamics for $(\theta_t, \bar{\theta}_t)^\mathsf{T}$ in state space form, with transition equation

$$\left(\begin{array}{c} \theta_t \\ \bar{\theta}_t \end{array} \right) = \left[\begin{array}{cc} \rho & 0 \\ k_1\rho & (1-k_1)\rho \end{array} \right] \left(\begin{array}{c} \theta_{t-1} \\ \bar{\theta}_{t-1} \end{array} \right) + \left[\begin{array}{c} 1 \\ k_1 \end{array} \right] u_t$$

and measurement equation

$$z_{i,t} = (1\ ,\ 0) \left(\begin{array}{c} \theta_t \\ \bar{\theta}_t \end{array} \right) + \eta_{i,t}.$$

The stationary covariance matrix for the state given the history of signals up to t, $Var((\theta_t, \bar{\theta}_t)^\mathsf{T} | \{s_{i,t-j}\}_{j=0}^{\infty})$ can now be derived with a standard Kalman filter.

7 Tables for robustness analysis

Table 1: Matching **cross-sectional dispersion** and **consensus price volatility**

	60	80	90	95	100	105	110	120	150	200
6	1.021	1.043	1.045	1.050	1.052	1.058	1.115	1.125	0.961	·
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.012)	(0.014)	·
12	1.026	1.050	1.039	1.047	1.056	1.049	1.058	1.103	0.988	·
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.013)	·
24	1.079	1.052	1.047	1.053	1.064	1.063	1.164	1.082	0.999	0.909
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.011)	(0.012)	(0.016)
36	1.058	1.040	1.043	1.048	1.052	1.059	1.060	1.061	1.013	0.928
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.014)
48	1.036	1.033	1.038	1.038	1.033	1.034	1.035	1.041	1.019	0.960
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.014)
60	0.992	1.028	1.041	1.039	1.038	1.037	1.040	1.043	1.014	1.003
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.015)
84	0.986	1.026	1.021	1.019	1.015	1.012	1.015	1.023	1.005	0.913
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.021)	(0.012)	(0.012)	(0.012)	(0.014)

(a) Matching cross-sectional dispersion

	60	80	90	95	100	105	110	120	150	200
6	1.437	1.058	1.138	1.053	1.045	1.401	1.155	1.242	2.595	·
	(0.271)	(0.243)	(0.294)	(0.224)	(0.277)	(0.780)	(0.315)	(0.213)	(0.629)	·
12	1.110	1.028	1.117	1.320	1.104	0.990	1.120	1.014	2.573	·
	(0.264)	(0.201)	(0.313)	(0.553)	(0.252)	(0.219)	(0.263)	(0.228)	(0.755)	·
24	1.086	1.030	1.050	1.413	1.213	1.033	1.095	1.183	1.483	3.635
	(0.286)	(0.203)	(0.214)	(0.733)	(0.484)	(0.290)	(0.324)	(0.394)	(0.476)	(2.366)
36	1.019	1.158	1.049	2.062	1.199	0.931	1.383	1.017	1.061	1.761
	(0.214)	(0.593)	(0.336)	(1.594)	(0.365)	(0.158)	(0.644)	(0.254)	(0.347)	(0.379)
48	0.987	1.203	1.090	0.985	1.086	1.027	1.346	1.011	0.968	1.490
	(0.203)	(0.561)	(0.327)	(0.203)	(0.339)	(0.229)	(0.838)	(0.244)	(0.246)	(0.420)
60	1.296	1.373	1.157	1.009	1.106	1.043	1.070	1.300	0.980	1.324
	(0.418)	(0.642)	(0.409)	(0.247)	(0.338)	(0.299)	(0.306)	(0.579)	(0.254)	(0.433)
84	0.942	1.149	1.142	1.098	0.968	1.029	0.989	1.054	1.045	1.055
	(0.179)	(0.526)	(0.379)	(0.341)	(0.181)	(0.222)	(0.209)	(0.265)	(0.265)	(0.234)

(b) Matching volatility consensus price

These two tables present the mean and standard deviation of the ratio of the raw moments of the data versus the model implied moments for each contract. The upper table displays the ratio of the model-implied cross-sectional dispersion versus the average cross-sectional standard deviation in the data. The lower table displays the ratio of the model-implied volatility of the consensus price to the empirical counterpart from the data. The model-implied volatility is given by the unconditional volatility of the average first-order belief plus σ_ϵ. The unconditional variance of $\bar{\theta}_t$ is the solution to a Lyapunov equation that defines the unconditional variance of the state. The first row and first column of each table denote the moneyness and time-to-expiration, respectively, of the options under consideration. The standard deviation of the posterior distribution of the ratios is given in parentheses below its mean (0.000 signifies standard deviations below 0.0005). The sample period of the data is January 2002 to December 2015.

Table 2: Model parameter estimates $\phi = \{\rho, \sigma_u, \sigma_\varepsilon, \sigma_\eta\}$ **(sub-sample 2006-2011)**

	60	80	90	95	100	105	110	120	150	200
6	0.941	0.901	0.913	0.954	0.903	0.901	0.911	0.952	0.952	·
	(0.026)	(0.045)	(0.047)	(0.058)	(0.037)	(0.039)	(0.045)	(0.018)	(0.027)	·
12	0.964	0.909	0.916	0.909	0.916	0.909	0.913	0.963	0.957	·
	(0.020)	(0.038)	(0.036)	(0.041)	(0.041)	(0.038)	(0.031)	(0.022)	(0.025)	·
24	0.960	0.919	0.916	0.919	0.921	0.925	0.922	0.916	0.949	0.948
	(0.018)	(0.032)	(0.038)	(0.037)	(0.037)	(0.034)	(0.036)	(0.034)	(0.021)	(0.025)
36	0.968	0.926	0.928	0.932	0.916	0.916	0.929	0.911	0.956	0.949
	(0.021)	(0.038)	(0.036)	(0.036)	(0.035)	(0.036)	(0.027)	(0.033)	(0.021)	(0.027)
48	0.961	0.920	0.916	0.923	0.911	0.909	0.947	0.917	0.932	0.946
	(0.018)	(0.032)	(0.035)	(0.037)	(0.038)	(0.039)	(0.045)	(0.033)	(0.039)	(0.026)
60	0.978	0.930	0.922	0.921	0.917	0.924	0.917	0.913	0.917	0.945
	(0.016)	(0.040)	(0.036)	(0.033)	(0.036)	(0.036)	(0.035)	(0.037)	(0.036)	(0.021)
84	0.964	0.915	0.916	0.921	0.916	0.916	0.933	0.915	0.913	0.948
	(0.018)	(0.033)	(0.031)	(0.036)	(0.034)	(0.037)	(0.033)	(0.033)	(0.034)	(0.027)

(a) Mean and standard deviation ρ

	60	80	90	95	100	105	110	120	150	200
6	0.085	0.110	0.117	0.125	0.131	0.140	0.148	0.107	0.162	·
	(0.002)	(0.009)	(0.010)	(0.011)	(0.011)	(0.012)	(0.012)	(0.002)	(0.006)	·
12	0.051	0.091	0.097	0.101	0.106	0.111	0.116	0.073	0.131	·
	(0.001)	(0.008)	(0.008)	(0.009)	(0.009)	(0.010)	(0.010)	(0.003)	(0.004)	·
24	0.044	0.080	0.084	0.087	0.090	0.093	0.097	0.103	0.079	0.137
	(0.001)	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.002)	(0.005)
36	0.040	0.072	0.075	0.077	0.079	0.082	0.084	0.089	0.063	0.100
	(0.001)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.002)	(0.003)
48	0.038	0.067	0.070	0.072	0.073	0.076	0.078	0.081	0.080	0.084
	(0.001)	(0.005)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.016)	(0.002)
60	0.036	0.063	0.065	0.066	0.067	0.069	0.070	0.073	0.082	0.069
	(0.001)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.002)
84	0.034	0.056	0.057	0.058	0.059	0.060	0.061	0.063	0.070	0.056
	(0.001)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)

(b) Mean and standard deviation σ_u

	60	80	90	95	100	105	110	120	150	200
6	0.104	0.001	0.001	0.001	0.001	0.002	0.003	0.152	0.325	·
	(0.011)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.015)	(0.029)	·
12	0.059	0.001	0.000	0.000	0.000	0.000	0.001	0.055	0.252	·
	(0.006)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.006)	(0.024)	·
24	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.098	0.226
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.009)	(0.021)
36	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.158
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.015)
48	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.116
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.015)	(0.012)
60	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.091
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.009)
84	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.066
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.007)

(c) Mean and standard deviation σ_ε

	60	80	90	95	100	105	110	120	150	200
6	0.091	0.021	0.015	0.013	0.013	0.017	0.026	0.109	0.321	·
	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.020)	·
12	0.039	0.015	0.011	0.010	0.009	0.011	0.015	0.036	0.220	·
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.010)	·
24	0.026	0.013	0.010	0.009	0.008	0.010	0.011	0.018	0.074	0.283
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.018)
36	0.022	0.012	0.009	0.008	0.008	0.009	0.010	0.015	0.039	0.159
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.008)
48	0.024	0.012	0.009	0.009	0.008	0.009	0.010	0.014	0.028	0.111
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.005)
60	0.024	0.012	0.010	0.009	0.009	0.009	0.010	0.013	0.022	0.080
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)
84	0.027	0.013	0.011	0.010	0.010	0.010	0.011	0.014	0.022	0.058
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.002)

(d) Mean and standard deviation σ_η

The panels in this table present the means and standard deviations (in parentheses) of the model parameter estimates. Panel (a) displays estimates of the persistence ρ of the AR1 process for the fundamental value. Panel (b) displays estimates of the standard deviation σ_u of the shock to the fundamental. Panel (c) displays the estimates of the standard deviation σ_ε of the noise in the consensus price. Panel (d) displays the estimates of the standard deviation of the noise σ_η in private signal. Estimates are obtained using MCMC methods assuming diffuse priors for all parameters. The first row and first column of each panel give moneyness and time-to-expiration, respectively, of the option contracts under consideration. The standard deviation of the posterior distribution of the parameter is given in parenthesis below its mean (0.000 signifies standard deviations below 0.0005). The sample period of the data is December 2006 to December 2011.

Table 3: Counterfactual experiments **(sub-sample 2006-2011)**

	60	80	90	95	100	105	110	120	150	200
6	1.44	0.06	0.01	0.01	0.00*	0.01	0.04	1.02	2.35	·
	(0.26)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.19)	(0.41)	·
12	0.67	0.03	0.01	0.00*	0.00*	0.00*	0.01	0.28	1.91	·
	(0.12)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.06)	(0.37)	·
24	0.50	0.03	0.01	0.00*	0.00*	0.00*	0.01	0.04	1.03	3.20
	(0.10)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.02)	(0.18)	(0.53)
36	0.51	0.03	0.01	0.01	0.00*	0.01	0.01	0.03	0.59	2.24
	(0.10)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.11)	(0.38)
48	0.58	0.04	0.01	0.01	0.01	0.01	0.01	0.03	0.33	1.91
	(0.12)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.13)	(0.34)
60	0.67	0.06	0.02	0.01	0.01	0.01	0.02	0.04	0.19	1.54
	(0.13)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.06)	(0.27)
84	0.93	0.11	0.05	0.04	0.03	0.04	0.05	0.10	0.32	1.41
	(0.17)	(0.04)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)	(0.11)	(0.25)

(a) *Decrease in valuation uncertainty*: Δ_1^p

	60	80	90	95	100	105	110	120	150	200
6	9.97	0.34	0.08	0.04	0.02	0.05	0.23	7.34	15.61	·
	(1.57)	(0.13)	(0.06)	(0.05)	(0.05)	(0.05)	(0.12)	(1.18)	(2.24)	·
12	4.96	0.19	0.04	0.02	0.02	0.03	0.07	2.22	12.86	·
	(0.84)	(0.08)	(0.07)	(0.05)	(0.06)	(0.04)	(0.05)	(0.42)	(2.06)	·
24	3.77	0.17	0.04	0.03	0.02	0.03	0.05	0.25	7.40	20.56
	(0.68)	(0.07)	(0.05)	(0.04)	(0.05)	(0.04)	(0.07)	(0.10)	(1.13)	(2.72)
36	3.81	0.17	0.05	0.04	0.03	0.04	0.06	0.19	4.39	14.80
	(0.69)	(0.07)	(0.06)	(0.06)	(0.04)	(0.06)	(0.07)	(0.10)	(0.74)	(2.11)
48	4.34	0.25	0.08	0.05	0.04	0.05	0.08	0.20	2.19	12.79
	(0.77)	(0.10)	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)	(0.08)	(1.06)	(1.92)
60	4.98	0.33	0.13	0.09	0.07	0.08	0.11	0.25	1.08	10.57
	(0.86)	(0.12)	(0.06)	(0.06)	(0.06)	(0.05)	(0.06)	(0.10)	(0.38)	(1.60)
84	6.67	0.65	0.29	0.22	0.20	0.23	0.31	0.59	1.84	9.72
	(1.09)	(0.23)	(0.12)	(0.09)	(0.08)	(0.09)	(0.12)	(0.20)	(0.71)	(1.49)

(b) *Decrease in strategic uncertainty*: Δ_2^p

	60	80	90	95	100	105	110	120	150	200
6	8.82	-0.03	-0.02	0.00*	-0.02	0.00*	-0.01	8.27	22.75	·
	(7.19)	(2.23)	(2.12)	(2.12)	(2.11)	(2.10)	(2.41)	(7.94)	(20.23)	·
12	4.48	-0.04	0.01	0.00*	0.03	0.00*	-0.01	1.17	19.12	·
	(2.98)	(2.16)	(2.26)	(2.26)	(2.29)	(2.15)	(2.14)	(3.06)	(15.08)	·
24	2.19	-0.02	0.02	-0.01	0.01	0.00*	0.02	-0.03	6.86	23.10
	(2.67)	(2.20)	(2.20)	(2.25)	(2.30)	(2.21)	(2.20)	(2.21)	(5.65)	(15.83)
36	1.87	0.00*	0.01	0.04	0.02	0.03	0.01	-0.02	2.24	17.22
	(2.59)	(2.22)	(2.32)	(2.40)	(2.29)	(2.37)	(2.27)	(2.21)	(3.40)	(10.00)
48	2.58	0.01	0.01	0.01	0.01	0.01	0.01	-0.01	0.36	12.93
	(2.66)	(2.27)	(2.36)	(2.35)	(2.30)	(2.35)	(2.23)	(2.23)	(3.68)	(7.73)
60	3.19	0.03	0.02	0.02	0.04	0.00*	-0.01	-0.02	-0.03	10.27
	(2.64)	(2.29)	(2.30)	(2.32)	(2.41)	(2.35)	(2.27)	(2.28)	(2.68)	(5.95)
84	4.92	0.01	-0.01	0.01	0.00*	-0.01	0.00*	0.00*	0.10	8.21
	(2.75)	(2.48)	(2.46)	(2.44)	(2.42)	(2.46)	(2.47)	(2.47)	(2.94)	(4.19)

(c) *Reduction in valuation Uncertainty*: Δ_1^θ

	60	80	90	95	100	105	110	120	150	200
6	32.59	-0.05	-0.03	-0.01	-0.03	-0.02	-0.05	32.26	60.78	·
	(4.44)	(2.25)	(2.07)	(2.05)	(2.05)	(2.08)	(2.74)	(5.16)	(5.64)	·
12	19.27	-0.04	0.00*	-0.01	0.02	-0.01	-0.02	5.83	56.21	·
	(2.73)	(2.04)	(2.09)	(2.13)	(2.16)	(2.07)	(2.12)	(3.26)	(5.31)	·
24	10.04	-0.03	0.01	-0.02	0.01	-0.01	0.00*	-0.05	27.36	57.33
	(2.58)	(2.07)	(2.09)	(2.12)	(2.16)	(2.10)	(2.07)	(2.17)	(4.14)	(4.23)
36	8.30	-0.01	0.00*	0.03	0.01	0.02	0.00*	-0.04	10.08	50.99
	(2.57)	(2.07)	(2.17)	(2.23)	(2.15)	(2.21)	(2.11)	(2.11)	(3.29)	(3.99)
48	11.48	0.00*	0.01	0.00*	0.00*	0.00*	0.01	-0.02	1.48	42.73
	(2.62)	(2.08)	(2.19)	(2.20)	(2.16)	(2.18)	(2.11)	(2.10)	(5.92)	(4.35)
60	13.68	0.00*	0.00*	0.01	0.03	0.00*	-0.02	-0.03	-0.07	36.63
	(2.59)	(2.09)	(2.14)	(2.16)	(2.23)	(2.19)	(2.13)	(2.12)	(2.55)	(3.74)
84	20.26	-0.01	-0.02	0.00*	-0.01	-0.02	-0.01	-0.02	-0.19	30.58
	(2.61)	(2.21)	(2.24)	(2.25)	(2.24)	(2.26)	(2.25)	(2.22)	(2.62)	(3.28)

(d) *Reduction in Strategic Uncertainty*: Δ_2^θ

The panels in this table present the counterfactual percentage decreases in valuation and strategic uncertainty. The two top panels display the reductions in uncertainties when comparing a setting without consensus price to a setting with consensus price. Panel (a) presents the results for the percentage decrease in **valuation uncertainty**, Δ_1^p. Panel (b) shows the percentage increase in **strategic uncertainty**, Δ_2^p. The lower panels shows the counterfactual percentage reductions in valuation and strategic uncertainty when comparing the current information structure to an information structure with a consensus price that perfectly reveals last period's state. Panel (c) shows percentage reduction in **valuation uncertainty**, Δ_1^θ. Panel (d) shows the percentage reduction in **strategic uncertainty**, Δ_2^θ. The first row and first column of each table give moneyness and time-to-expiration, respectively, of the options under consideration. The standard deviations of the posterior distribution of the parameter is given in parentheses below the means (0.00 signifies standard deviations below 0.005). The sample period is from December 2006 to December 2011.

Table 4: Model parameter estimates $\phi = \{\rho, \sigma_u, \sigma_\varepsilon, \sigma_\eta\}$ **(sub-sample 2010-2015)**

	60	80	90	95	100	105	110	120	150	200
6	0.910	0.801	0.805	0.811	0.838	0.827	0.829	0.898	0.900	·
	(0.044)	(0.071)	(0.062)	(0.063)	(0.081)	(0.066)	(0.068)	(0.037)	(0.050)	·
12	0.893	0.895	0.861	0.878	0.861	0.899	0.883	0.853	0.938	·
	(0.057)	(0.062)	(0.046)	(0.064)	(0.053)	(0.071)	(0.062)	(0.063)	(0.029)	·
24	0.908	0.917	0.880	0.858	0.909	0.875	0.870	0.862	0.916	0.972
	(0.058)	(0.061)	(0.049)	(0.052)	(0.062)	(0.051)	(0.065)	(0.057)	(0.036)	(0.019)
36	0.890	0.892	0.896	0.880	0.873	0.872	0.859	0.856	0.936	0.943
	(0.046)	(0.051)	(0.055)	(0.053)	(0.061)	(0.045)	(0.058)	(0.066)	(0.037)	(0.027)
48	0.916	0.888	0.884	0.867	0.887	0.865	0.881	0.860	0.888	0.924
	(0.044)	(0.048)	(0.055)	(0.049)	(0.058)	(0.054)	(0.058)	(0.063)	(0.036)	(0.034)
60	0.927	0.909	0.894	0.882	0.896	0.874	0.873	0.836	0.915	0.934
	(0.054)	(0.057)	(0.046)	(0.049)	(0.054)	(0.049)	(0.061)	(0.056)	(0.047)	(0.040)
84	0.909	0.888	0.898	0.880	0.893	0.892	0.862	0.890	0.813	0.919
	(0.048)	(0.044)	(0.044)	(0.047)	(0.041)	(0.049)	(0.044)	(0.065)	(0.063)	(0.033)

(a) Mean and standard deviation ρ

	60	80	90	95	100	105	110	120	150	200
6	0.066	0.099	0.108	0.120	0.135	0.150	0.153	0.130	0.183	·
	(0.002)	(0.008)	(0.010)	(0.011)	(0.012)	(0.014)	(0.013)	(0.003)	(0.009)	·
12	0.070	0.081	0.089	0.095	0.101	0.109	0.115	0.121	0.130	·
	(0.006)	(0.007)	(0.008)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.005)	·
24	0.061	0.070	0.075	0.079	0.083	0.087	0.091	0.097	0.083	0.118
	(0.005)	(0.006)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.002)	(0.006)
36	0.056	0.062	0.067	0.069	0.072	0.074	0.077	0.082	0.061	0.109
	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.002)	(0.005)
48	0.054	0.059	0.062	0.064	0.066	0.068	0.071	0.075	0.057	0.093
	(0.004)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.002)	(0.004)
60	0.051	0.055	0.057	0.058	0.060	0.062	0.064	0.066	0.050	0.072
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.002)	(0.003)
84	0.046	0.048	0.050	0.051	0.052	0.053	0.054	0.056	0.062	0.053
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.002)

(b) Mean and standard deviation σ_u

	60	80	90	95	100	105	110	120	150	200
6	0.064	0.000	0.000	0.000	0.000	0.001	0.002	0.173	0.325	·
	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.019)	(0.034)	·
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.299	·
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.031)	·
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.128	0.348
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.014)	(0.032)
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.067	0.246
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.007)	(0.024)
48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.177
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.006)	(0.018)
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.129
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.013)
84	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.088
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.010)

(c) Mean and standard deviation σ_ε

	60	80	90	95	100	105	110	120	150	200
6	0.049	0.019	0.012	0.010	0.008	0.015	0.031	0.159	0.328	·
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.008)	(0.030)	·
12	0.016	0.010	0.008	0.007	0.006	0.008	0.012	0.029	0.269	·
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.018)	·
24	0.012	0.008	0.006	0.006	0.005	0.007	0.008	0.014	0.101	0.423
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.037)
36	0.012	0.008	0.007	0.006	0.006	0.007	0.008	0.012	0.049	0.270
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.021)
48	0.015	0.010	0.009	0.008	0.008	0.009	0.010	0.013	0.039	0.175
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.012)
60	0.015	0.011	0.009	0.009	0.009	0.009	0.010	0.012	0.030	0.111
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.007)
84	0.015	0.010	0.010	0.010	0.010	0.010	0.010	0.012	0.020	0.071
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.004)

(d) Mean and standard deviation σ_η

The panels in this table present the means and standard deviations (in parentheses) of the model parameter estimates. Panel (a) displays estimates of the persistence ρ of the AR1 process for the fundamental value. Panel (b) displays estimates of the standard deviation σ_u of the shock to the fundamental. Panel (c) displays the estimates of the standard deviation σ_ε of the noise in the consensus price. Panel (d) displays the estimates of the standard deviation of the noise σ_η in private signal. Estimates are obtained using MCMC methods assuming diffuse priors for all parameters. The first row and first column of each panel give moneyness and time-to-expiration, respectively, of the option contracts under consideration. The standard deviation of the posterior distribution of the parameter is given in parenthesis below its mean (0.000 signifies standard deviations below 0.0005). The sample period of the data is December 2010 to February 2015.

Table 5: Counterfactual experiments **(sub-sample 2010-2015)**

	60	80	90	95	100	105	110	120	150	200
6	0.71	0.04	0.01	0.00*	0.00*	0.00*	0.05	1.51	1.91	·
	(0.15)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.31)	(0.47)	·
12	0.10	0.01	0.00*	0.00*	0.00*	0.00*	0.00*	0.11	1.94	·
	(0.04)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.04)	(0.43)	·
24	0.06	0.01	0.00*	0.00*	0.00*	0.00*	0.00*	0.02	1.25	3.49
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.25)	(0.63)
36	0.07	0.01	0.00*	0.00*	0.00*	0.00*	0.00*	0.02	0.77	2.63
	(0.03)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.15)	(0.50)
48	0.22	0.04	0.02	0.01	0.01	0.01	0.01	0.03	0.63	2.08
	(0.08)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.13)	(0.41)
60	0.27	0.06	0.03	0.02	0.02	0.02	0.02	0.04	0.58	1.69
	(0.10)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.13)	(0.32)
84	0.37	0.09	0.06	0.05	0.05	0.05	0.05	0.07	0.29	1.36
	(0.13)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.10)	(0.27)

(a) *Decrease in valuation uncertainty*: Δ_1^p

	60	80	90	95	100	105	110	120	150	200
6	5.31	0.25	0.03	0.01	0.00*	0.02	0.33	10.63	13.43	·
	(0.96)	(0.13)	(0.05)	(0.05)	(0.05)	(0.06)	(0.15)	(1.79)	(2.39)	·
12	0.57	0.07	0.01	0.01	0.00*	0.01	0.03	0.64	13.43	·
	(0.21)	(0.06)	(0.05)	(0.08)	(0.04)	(0.05)	(0.07)	(0.24)	(2.36)	·
24	0.35	0.06	0.01	0.01	0.01	0.01	0.02	0.11	8.96	22.99
	(0.14)	(0.06)	(0.04)	(0.06)	(0.04)	(0.04)	(0.06)	(0.07)	(1.56)	(3.26)
36	0.43	0.07	0.03	0.02	0.01	0.02	0.03	0.09	5.70	17.87
	(0.17)	(0.05)	(0.08)	(0.05)	(0.04)	(0.04)	(0.06)	(0.07)	(0.98)	(2.70)
48	1.26	0.23	0.09	0.07	0.06	0.06	0.08	0.20	4.74	14.35
	(0.49)	(0.09)	(0.05)	(0.05)	(0.05)	(0.06)	(0.06)	(0.10)	(0.86)	(2.28)
60	1.55	0.36	0.17	0.14	0.13	0.12	0.14	0.26	4.32	11.70
	(0.56)	(0.15)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.11)	(0.84)	(1.86)
84	2.09	0.51	0.34	0.30	0.31	0.29	0.29	0.42	1.64	9.65
	(0.78)	(0.20)	(0.13)	(0.12)	(0.12)	(0.12)	(0.12)	(0.16)	(0.60)	(1.68)

(b) *Decrease in strategic uncertainty*: Δ_2^p

	60	80	90	95	100	105	110	120	150	200
6	3.53	-0.02	-0.03	0.00*	0.02	-0.02	-0.09	10.06	18.17	·
	(4.19)	(2.40)	(2.35)	(2.43)	(2.53)	(2.29)	(3.16)	(12.87)	(19.41)	·
12	-0.04	-0.02	0.00*	0.04	0.03	0.00*	-0.01	-0.08	23.95	·
	(2.60)	(2.47)	(2.46)	(2.90)	(2.73)	(2.46)	(2.46)	(3.10)	(17.00)	·
24	-0.01	0.00*	0.02	0.02	0.03	0.01	0.02	0.00*	11.11	39.20
	(2.59)	(2.56)	(2.68)	(2.69)	(2.82)	(2.61)	(2.55)	(2.40)	(6.41)	(16.19)
36	0.00*	-0.01	0.03	0.01	0.02	0.01	0.01	0.01	4.56	28.43
	(2.66)	(2.61)	(2.73)	(2.68)	(2.70)	(2.67)	(2.66)	(2.51)	(4.19)	(12.86)
48	0.01	-0.02	0.00*	-0.02	-0.01	0.01	-0.02	0.00*	2.66	21.00
	(2.86)	(2.55)	(2.56)	(2.57)	(2.63)	(2.59)	(2.57)	(2.55)	(3.45)	(10.18)
60	0.03	-0.01	0.01	0.00*	-0.01	0.01	-0.04	0.01	1.80	16.60
	(2.93)	(2.70)	(2.68)	(2.66)	(2.64)	(2.65)	(2.61)	(2.62)	(3.27)	(7.50)
84	0.02	-0.03	-0.01	-0.02	0.00*	-0.01	-0.02	-0.04	-0.06	12.95
	(3.18)	(2.86)	(2.81)	(2.82)	(2.80)	(2.83)	(2.84)	(2.77)	(3.19)	(4.66)

(c) *Reduction in valuation Uncertainty*: Δ_1^θ

	60	80	90	95	100	105	110	120	150	200
6	15.81	-0.03	-0.04	-0.01	0.01	-0.03	-0.11	37.29	55.41	·
	(3.71)	(2.30)	(2.27)	(2.32)	(2.41)	(2.29)	(3.59)	(7.03)	(6.35)	·
12	-0.04	-0.02	-0.01	0.03	0.02	-0.01	-0.02	-0.11	64.19	·
	(2.36)	(2.32)	(2.35)	(2.70)	(2.63)	(2.36)	(2.33)	(3.48)	(4.62)	·
24	-0.02	-0.01	0.01	0.01	0.02	0.01	0.01	-0.01	39.91	70.15
	(2.38)	(2.38)	(2.54)	(2.55)	(2.70)	(2.49)	(2.40)	(2.29)	(3.72)	(3.28)
36	-0.01	-0.02	0.02	0.00*	0.02	0.01	0.00*	0.00*	19.48	66.18
	(2.41)	(2.44)	(2.55)	(2.52)	(2.59)	(2.53)	(2.51)	(2.36)	(3.52)	(3.34)
48	-0.12	-0.03	0.00*	-0.02	-0.01	0.01	-0.03	-0.02	12.10	58.56
	(2.54)	(2.36)	(2.40)	(2.43)	(2.48)	(2.43)	(2.41)	(2.37)	(3.24)	(3.57)
60	-0.06	-0.02	0.00*	-0.01	-0.01	0.00*	-0.04	0.00*	8.41	51.76
	(2.54)	(2.42)	(2.46)	(2.46)	(2.47)	(2.46)	(2.44)	(2.41)	(3.20)	(3.37)
84	-0.18	-0.03	-0.02	-0.03	-0.02	-0.02	-0.03	-0.04	-0.07	44.61
	(2.77)	(2.56)	(2.56)	(2.55)	(2.55)	(2.57)	(2.58)	(2.52)	(2.75)	(3.07)

(d) *Reduction in Strategic Uncertainty*: Δ_2^θ

The panels in this table present the counterfactual percentage decreases in valuation and strategic uncertainty. The two top panels display the reductions in uncertainties when comparing a setting without consensus price to a setting with consensus price. Panel (a) presents the results for the percentage decrease in **valuation uncertainty**, Δ_1^p. Panel (b) shows the percentage increase in **strategic uncertainty**, Δ_2^p. The lower panels shows the counterfactual percentage reductions in valuation and strategic uncertainty when comparing the current information structure to an information structure with a consensus price that perfectly reveals last period's state. Panel (c) shows percentage reduction in **valuation uncertainty**, Δ_1^θ. Panel (d) shows the percentage reduction in **strategic uncertainty**, Δ_2^θ. The first row and first column of each table give moneyness and time-to-expiration, respectively, of the options under consideration. The standard deviations of the posterior distribution of the parameter is given in parentheses below the means (0.00 signifies standard deviations below 0.005). The sample period is from December 2010 to February 2015.

Table 6: Model parameter estimates $\phi = \{\rho, \sigma_u, \sigma_\varepsilon, \sigma_\eta\}$ **(Dealers banks submitted >40% of sample period)**

	60	80	90	95	100	105	110	120	150	200
6	0.951	0.906	0.923	0.912	0.912	0.913	0.916	0.946	0.945	·
	(0.021)	(0.028)	(0.039)	(0.028)	(0.031)	(0.033)	(0.032)	(0.024)	(0.021)	·
12	0.963	0.938	0.949	0.930	0.921	0.932	0.929	0.921	0.954	·
	(0.017)	(0.036)	(0.038)	(0.027)	(0.026)	(0.028)	(0.029)	(0.025)	(0.017)	·
24	0.972	0.934	0.934	0.936	0.939	0.936	0.937	0.916	0.949	0.969
	(0.014)	(0.023)	(0.026)	(0.026)	(0.029)	(0.027)	(0.029)	(0.025)	(0.019)	(0.019)
36	0.968	0.939	0.942	0.936	0.932	0.943	0.927	0.941	0.963	0.969
	(0.013)	(0.027)	(0.027)	(0.022)	(0.025)	(0.029)	(0.029)	(0.036)	(0.017)	(0.024)
48	0.978	0.948	0.935	0.933	0.931	0.937	0.933	0.926	0.956	0.940
	(0.014)	(0.025)	(0.024)	(0.023)	(0.024)	(0.027)	(0.027)	(0.024)	(0.021)	(0.025)
60	0.972	0.938	0.936	0.938	0.930	0.933	0.938	0.927	0.921	0.946
	(0.013)	(0.025)	(0.025)	(0.027)	(0.025)	(0.024)	(0.028)	(0.028)	(0.028)	(0.027)
84	0.975	0.943	0.941	0.943	0.938	0.945	0.930	0.941	0.928	0.963
	(0.015)	(0.024)	(0.023)	(0.028)	(0.025)	(0.027)	(0.023)	(0.030)	(0.026)	(0.018)

(a) Mean and standard deviation ρ

	60	80	90	95	100	105	110	120	150	200
6	0.080	0.093	0.101	0.109	0.119	0.130	0.133	0.113	0.168	·
	(0.001)	(0.005)	(0.006)	(0.006)	(0.007)	(0.008)	(0.007)	(0.002)	(0.006)	·
12	0.047	0.077	0.084	0.088	0.093	0.099	0.104	0.109	0.140	·
	(0.001)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.003)	·
24	0.041	0.068	0.073	0.076	0.079	0.082	0.085	0.091	0.079	0.128
	(0.001)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)	(0.005)
36	0.037	0.062	0.066	0.068	0.070	0.073	0.075	0.080	0.061	0.107
	(0.001)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.001)	(0.003)
48	0.035	0.059	0.062	0.064	0.066	0.068	0.070	0.074	0.057	0.097
	(0.001)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.001)	(0.002)
60	0.033	0.056	0.059	0.060	0.061	0.063	0.065	0.068	0.077	0.089
	(0.001)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.002)
84	0.033	0.052	0.054	0.055	0.056	0.057	0.058	0.060	0.068	0.058
	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.001)

(b) Mean and standard deviation σ_u

	60	80	90	95	100	105	110	120	150	200
6	0.113	0.000	0.000	0.000	0.000	0.002	0.004	0.137	0.338	·
	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.009)	(0.021)	·
12	0.054	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.260	·
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.016)	·
24	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.108	0.226
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.008)	(0.014)
36	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.166
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)	(0.011)
48	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.112
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.008)
60	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.077
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.005)
84	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.059
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)

(c) Mean and standard deviation σ_ε

	60	80	90	95	100	105	110	120	150	200
6	0.095	0.019	0.013	0.012	0.012	0.017	0.028	0.131	0.385	·
	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)	(0.021)	·
12	0.041	0.013	0.010	0.009	0.009	0.011	0.014	0.030	0.300	·
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.013)	·
24	0.026	0.011	0.008	0.008	0.008	0.009	0.010	0.015	0.094	0.343
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.020)
36	0.022	0.010	0.008	0.008	0.008	0.008	0.010	0.014	0.047	0.213
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.011)
48	0.024	0.011	0.009	0.008	0.008	0.009	0.010	0.013	0.035	0.152
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.007)
60	0.025	0.011	0.009	0.009	0.009	0.009	0.010	0.012	0.024	0.112
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)
84	0.028	0.013	0.011	0.011	0.010	0.011	0.011	0.013	0.022	0.063
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)

(d) Mean and standard deviation σ_η

The panels in this table present the means and standard deviations (in parentheses) of the model parameter estimates. Panel (a) displays estimates of the persistence ρ of the AR1 process for the fundamental value. Panel (b) displays estimates of the standard deviation σ_u of the shock to the fundamental. Panel (c) displays the estimates of the standard deviation σ_ε of the noise in the consensus price. Panel (d) displays the estimates of the standard deviation of the noise σ_η in private signal. Estimates are obtained using MCMC methods assuming diffuse priors for all parameters. The first row and first column of each panel give moneyness and time-to-expiration, respectively, of the option contracts under consideration. The standard deviation of the posterior distribution of the parameter is given in parenthesis below its mean (0.000 signifies standard deviations below 0.0005). The sample period of the data is December 2010 to February 2015. Dealers banks must have submitted to at least 40% of the full sample period to be included.

Table 7: Counterfactual experiments **(Dealers banks submitted >40% of sample period)**

	60	80	90	95	100	105	110	120	150	200
6	1.50	0.07	0.01	0.01	0.00*	0.01	0.07	1.75	2.79	·
	(0.19)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.21)	(0.35)	·
12	0.94	0.03	0.01	0.01	0.00*	0.01	0.01	0.19	2.96	·
	(0.13)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.36)	·
24	0.80	0.02	0.01	0.01	0.00*	0.01	0.01	0.03	1.54	4.50
	(0.11)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.19)	(0.52)
36	0.78	0.03	0.01	0.01	0.01	0.01	0.01	0.04	1.00	3.54
	(0.11)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.13)	(0.42)
48	0.85	0.05	0.02	0.01	0.01	0.01	0.02	0.04	0.78	3.24
	(0.11)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.11)	(0.39)
60	0.91	0.06	0.02	0.02	0.02	0.02	0.02	0.04	0.33	3.25
	(0.12)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.09)	(0.37)
84	1.20	0.15	0.07	0.06	0.05	0.05	0.06	0.09	0.37	2.00
	(0.16)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.09)	(0.25)

(a) *Decrease in valuation uncertainty*: Δ_1^p

	60	80	90	95	100	105	110	120	150	200
6	10.34	0.42	0.08	0.04	0.03	0.08	0.44	11.82	18.59	·
	(1.14)	(0.14)	(0.04)	(0.07)	(0.06)	(0.06)	(0.14)	(1.22)	(1.84)	·
12	6.81	0.20	0.05	0.03	0.02	0.04	0.08	1.12	19.23	·
	(0.80)	(0.07)	(0.05)	(0.04)	(0.06)	(0.05)	(0.06)	(0.30)	(1.86)	·
24	5.77	0.14	0.05	0.03	0.03	0.03	0.06	0.18	10.57	27.83
	(0.67)	(0.05)	(0.06)	(0.05)	(0.04)	(0.05)	(0.06)	(0.06)	(1.14)	(2.46)
36	5.58	0.17	0.06	0.04	0.04	0.05	0.07	0.21	7.09	21.94
	(0.67)	(0.07)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.07)	(0.82)	(2.01)
48	6.10	0.29	0.11	0.07	0.06	0.07	0.10	0.25	5.65	20.31
	(0.72)	(0.09)	(0.07)	(0.06)	(0.04)	(0.06)	(0.07)	(0.09)	(0.68)	(1.91)
60	6.51	0.36	0.14	0.11	0.10	0.10	0.13	0.23	1.91	19.88
	(0.75)	(0.10)	(0.05)	(0.07)	(0.04)	(0.06)	(0.07)	(0.07)	(0.53)	(1.79)
84	8.39	0.85	0.40	0.33	0.31	0.31	0.34	0.51	2.08	13.13
	(0.95)	(0.20)	(0.10)	(0.09)	(0.08)	(0.09)	(0.09)	(0.13)	(0.54)	(1.38)

(b) *Decrease in strategic uncertainty*: Δ_2^p

	60	80	90	95	100	105	110	120	150	200
6	11.23	-0.01	0.00*	0.00*	0.01	-0.02	-0.04	9.94	26.04	·
	(7.45)	(1.75)	(1.64)	(1.71)	(1.70)	(1.69)	(2.20)	(10.24)	(21.58)	·
12	5.84	0.01	0.01	0.02	0.02	0.02	0.00*	-0.06	24.67	·
	(2.73)	(1.70)	(1.80)	(1.84)	(1.87)	(1.79)	(1.66)	(2.66)	(17.89)	·
24	2.65	0.00*	0.02	0.02	0.02	0.02	0.02	0.00*	10.86	30.07
	(2.03)	(1.77)	(1.99)	(1.96)	(2.00)	(1.98)	(1.89)	(1.71)	(5.84)	(16.27)
36	2.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	4.06	22.95
	(2.01)	(1.82)	(1.94)	(1.93)	(1.96)	(1.86)	(1.74)	(1.75)	(3.36)	(11.26)
48	3.08	0.01	0.01	0.02	0.02	0.01	0.00*	0.00*	2.08	15.59
	(2.00)	(1.84)	(1.92)	(1.97)	(1.89)	(1.88)	(1.83)	(1.81)	(2.42)	(9.23)
60	4.03	0.00*	0.02	-0.02	0.02	0.02	0.02	0.01	0.02	10.51
	(2.01)	(1.91)	(1.88)	(1.93)	(1.92)	(1.95)	(1.86)	(1.81)	(2.27)	(7.13)
84	5.62	-0.01	0.01	0.01	0.01	0.02	0.02	0.00*	-0.01	8.93
	(2.14)	(1.96)	(1.95)	(1.90)	(1.93)	(1.94)	(1.91)	(1.89)	(2.20)	(4.40)

(c) *Reduction in valuation Uncertainty*: Δ_1^θ

	60	80	90	95	100	105	110	120	150	200
6	39.31	-0.02	-0.01	-0.01	-0.01	-0.03	-0.07	35.56	63.09	·
	(3.77)	(1.76)	(1.60)	(1.59)	(1.60)	(1.81)	(2.59)	(5.58)	(4.54)	·
12	23.48	0.00*	0.01	0.01	0.01	0.00*	-0.01	-0.09	60.49	·
	(2.27)	(1.59)	(1.67)	(1.69)	(1.69)	(1.65)	(1.64)	(3.19)	(4.03)	·
24	11.20	0.00*	0.01	0.01	0.02	0.01	0.01	-0.01	38.15	59.40
	(1.93)	(1.64)	(1.80)	(1.79)	(1.85)	(1.79)	(1.71)	(1.64)	(3.30)	(2.88)
36	8.52	0.01	0.00*	0.01	0.02	0.01	0.00*	0.00*	16.79	55.51
	(1.99)	(1.64)	(1.78)	(1.77)	(1.81)	(1.73)	(1.63)	(1.61)	(2.87)	(3.17)
48	12.98	0.00*	0.00*	0.01	0.01	0.01	-0.01	-0.02	8.94	44.29
	(1.92)	(1.65)	(1.72)	(1.78)	(1.74)	(1.72)	(1.67)	(1.63)	(2.30)	(3.62)
60	16.58	-0.01	0.00*	-0.02	0.01	0.01	0.01	-0.01	-0.13	32.53
	(1.90)	(1.69)	(1.69)	(1.74)	(1.75)	(1.76)	(1.70)	(1.65)	(2.32)	(3.60)
84	21.86	-0.02	0.00*	0.01	0.00*	0.00*	0.01	-0.01	-0.10	31.21
	(1.95)	(1.71)	(1.73)	(1.72)	(1.74)	(1.73)	(1.72)	(1.70)	(2.02)	(2.83)

(d) *Reduction in Strategic Uncertainty*: Δ_2^θ

The panels in this table present the counterfactual percentage decreases in valuation and strategic uncertainty. The two top panels display the reductions in uncertainties when comparing a setting without consensus price to a setting with consensus price. Panel (a) presents the results for the percentage decrease in **valuation uncertainty**, Δ_1^p. Panel (b) shows the percentage increase in **strategic uncertainty**, Δ_2^p. The lower panels shows the counterfactual percentage reductions in valuation and strategic uncertainty when comparing the current information structure to an information structure with a consensus price that perfectly reveals last period's state. Panel (c) shows percentage reduction in **valuation uncertainty**, Δ_1^θ. Panel (d) shows the percentage reduction in **strategic uncertainty**, Δ_2^θ. The first row and first column of each table give moneyness and time-to-expiration, respectively, of the options under consideration. The standard deviations of the posterior distribution of the parameter is given in parentheses below the means (0.00 signifies standard deviations below 0.005). The sample period is from December 2002 to February 2015. Dealers banks must have submitted to at least 40% of the full sample period to be included.

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