

Financialisation and the aluminium market

Evidence from a DSGE model*

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Abstract

This paper investigates the extend and impact of financialisation on the aluminium market. I test the hypothesis that the inflow in commodity linked financial products led to banks being more integrated in financial markets and eventually abusing their market power to manipulate prices. This hypothesis is tested by identifying a corresponding storage demand shock using a structural model of the US economy with aluminium used in production. This dynamic stochastic general equilibrium model includes storage and frictions representing warehouse queues. The model is estimated on data for the US from 1987 to 2008 and the frictions representing warehouse queues are found to be significant. Furthermore, monetary policy has a secondary transmission channel in a model with storage. The results suggest that financialisation played a role in explaining aluminium market dynamics leading up to 2008 and had a negative impact on the economy.

Keywords: storage, financialisation, aluminium, sticky-price DSGE model, adjustment cost

JEL Classification: C68, E12, Q02

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Introduction

The [US Senate Permanent Subcommittee on Investigations \(2014\)](#) report highlighted that banks were involved in market manipulation of commodity markets and among others the market of aluminium. They were manipulating the price by using their dominant position in warehouses and inventories. A particular mechanism in the aluminium market is warehouse queues. Only a certain amount of aluminium can be stocked out of warehouses at a time. This leads to unsatisfied demand and higher price elasticity. This mechanism was used by banks, which owned London Metal Exchange (LME) warehouses¹, owned inventories and sold exposure to aluminium via financial products. Thereby, banks could take on exposure and manipulate the price accordingly by queueing. So called “merry-go-round” trades, where a bank shifted its own inventories from one LME warehouse to another, not necessarily LME, warehouse, were used to increase the queue, signal stronger demand to the market and increase the price. This manipulation is only possible because of banks strong market position in financial and physical trading markets, as well as their warehousing activities. This development came about with the financialisation of commodities markets in the early 2000’s. Banks took on the role of intermediaries and could thereby build up their dominant position. [Figure 1](#) shows how trading volumes in futures and options contracts on the LME continuously increased and grew even stronger after 2003.

[Cheng and Xiong \(2013\)](#) provide a comprehensive discussion about the influence of financialisation on commodity markets and conclude that the growing role of investment in commodity linked financial products had an impact on commodity price dynamics. More specifically, they argue that investors are unable to differentiate between financial and real demand given informational frictions and that this helps explain the price increase leading up to the peak in 2008 (see [Figure 2](#)).

Assuming that financialisation led to banks being more integrated in commodity markets and eventually manipulating prices via queues as laid out above, questions arise as to if and when it happened and what the impact was. A negative economic impact of financialisation would make it a relevant issue for policy makers and warrant their scrutiny.

¹LME warehouses are licensed by the London Metal Exchange and make up for the biggest part of inventories held at exchanges. Other market participants such as producers hold inventories as well and there is less transparency about those levels.

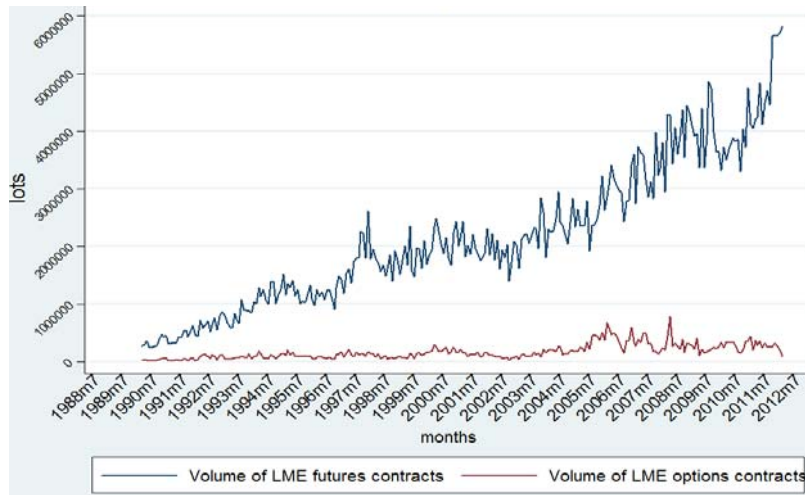


Figure 1: Monthly volumes of LME futures and options contracts. Source: Heumesser and Staritz (2013)



Figure 2: Primary Aluminium LME Spot [\$/mt]

Underlying this hypothesis is the notion that the demand signalled to the market reflected partially real demand and partially financial or speculative demand. In order to differentiate between the two I argue in favour of a structural model with an emphasis on the demand side. On the atheoretical side of the spectrum lie structural vector autoregressions (VAR). Lutz Kilian is one of the prominent authors regarding VARs connected to the oil market. In Kilian (2009) he investigates the oil market before the global financial crisis with a model including storage. He assigns little importance to oil market specific shocks to be a driver of the oil price. For the demand side he uses ocean freight rates as a proxy

for commodity related demand, which is at best a biased measure of demand for oil. Freight rates are strongly influenced by the shipping market and the cyclical shipbuilding. Therefore, they do not only represent global demand factors and are biased. Therefore, I argue in favour of dynamic stochastic general equilibrium (DSGE) models, which are more theory consistent and micro-founded. With the seminal work of [Smets and Wouters \(2007\)](#) this class of models became accepted not only as a model suitable for forecasting and policy analysis. DSGE models explicitly model demand and supply and are therefore a suitable tool to estimate the real demand for aluminium. The DSGE model used here builds on [Unalmis et al. \(2012\)](#) and [Tumen et al. \(2015\)](#). They model the US economy with oil used in consumption and production. Most importantly, they include storage in their model and identify a storage demand shock, which is orthogonal to the other demand side shocks.

I expand on these contributions along two dimensions in the context of aluminium. First, I reason that aluminium is only used in production and not in consumption as is the case for oil, where it is argued that heating and fuel is close enough to direct use of oil in consumption. Second, I model the queue mechanism outlined above by including a friction for changes in inventory levels. To the best of my knowledge this is the first contribution to investigate the extend and effect of financialisation in the aluminium market with a DSGE model.

The influence of financialisation, being the inflow of investment in commodity linked financial products, on commodity markets is contested within the literature. On the one hand, the argument goes that if this inflow had an influence we would have seen inventory levels increase due to the arbitrage possibility between future and spot markets. Since this did not happen, the influence of financialisation is dismissed and the demand fully identified as being real demand (see [Hamilton \(2009\)](#), [Kilian and Murphy \(2014\)](#)). On the other hand, there is a strand of literature arguing that informational frictions regarding the future and spot market or inventory levels explains that financial demand was mistaken as real demand. [Wright \(2011\)](#) analyses the grain market and concludes that the uncertainty about storage levels contributed to price volatility and changed the price reaction to supply and demand shocks. [Sockin and Xiong \(2015\)](#) find strong evidence that investment flows exacerbated price movements in 2008 by signalling strong global demand despite the onset of the recession.

My analysis with a DSGE model allows me to identify a storage demand shock, orthogonal to other supply and demand related shocks (government spending, monetary policy etc.), which explains the residual variation in the price and inventory levels. This shock can be interpreted as being a speculative demand shock as well as a precautionary demand shock (see [Alquist and Kilian \(2010\)](#)). Uncertainty about future aluminium supply would lead higher inventory levels because of precautionary demand and this would be captured in the storage demand shock.

The hypothesis that banks became more integrated in the aluminium market and used their dominant position to manipulate prices by using warehouse queues can be verified with the identification of the storage demand shock over time and the significance of the friction on warehouse stock outs.

I find that storage demand shocks played a major role in explaining aluminium price movements. The other demand side shocks had a relatively smaller influence on prices. The friction related to warehouse queues is found to be significantly different from zero and explains part of the inventory level stickiness. Furthermore, the presence of storage with queues changes the monetary policy transmission, because a monetary policy shock leads indirectly to lower inflation through the lower aluminium price. The model without storage estimates a larger role for demand side factors in explaining aluminium price movements, which is in line with the findings in the literature.

A storage demand shock has a negative impact on economic growth and increases interest rates and aluminium prices.

These findings confirm that financialisation had an impact on the aluminium market and partially explained the perceived high demand leading up to 2008. Furthermore, the impact of financialisation on the economy is small but negative.

Therefore, I argue that policy makers have good reason to regulate commodity markets, address the problem of queues and increase transparency about inventory levels.

The paper develops the argument in the following way. First, [Section 1](#) provides background information on aluminium. Next, [Section 2](#) describes the model and [Section 3](#) describes the data and estimation of the model. In [Section 4](#) I discuss the results of the estimated model and [Section 5](#) concludes.

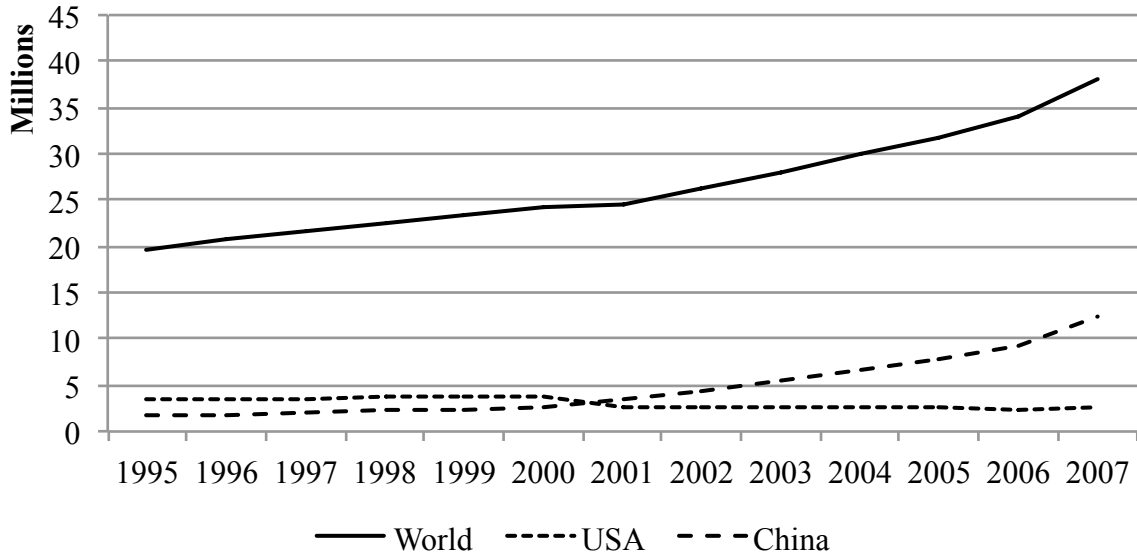


Figure 3: Yearly Aluminium Production [mt]

1 Background on Aluminium

Aluminium is won from aluminium ores (e.g. bauxite) using an energy intensive procedure or by recycling aluminium scrap. About 60% of quarterly supply in the US is stored in warehouses in 2015, of which a part is held in LME warehouses. Stock outs from these warehouses are subject to queues, which impede the immediate satisfaction of demand. This feature of the aluminium market helps explain the strong price reaction and muted inventory level changes. Figure 3 shows the production and Figure 4 the demand of primary aluminium for the world and the two largest producers, the US and China from 1995 onwards.² The United States were the largest consumer of aluminium up until 2003 and the largest producer up until 2001. Chinas fast economic expansion translated into strong demand for aluminium and a domestic aluminium industry catching up with this demand.

The simultaneously rising production and demand figures for China suggest that their demand is satisfied domestically. This is confirmed by looking at trade data. Figure 5 shows that Chinas metal imports did not grow in line with its demand. The US remained the biggest importer world wide. Thereby, it seems reasonable to assume that the US

²The aggregate demand, supply and export import data from the World Bureau of Metal Statistics goes back only to 1995 on an annual basis. The data used in the model estimation comes from the US Geological Survey and goes back to 1980 at a monthly frequency but only for the US.

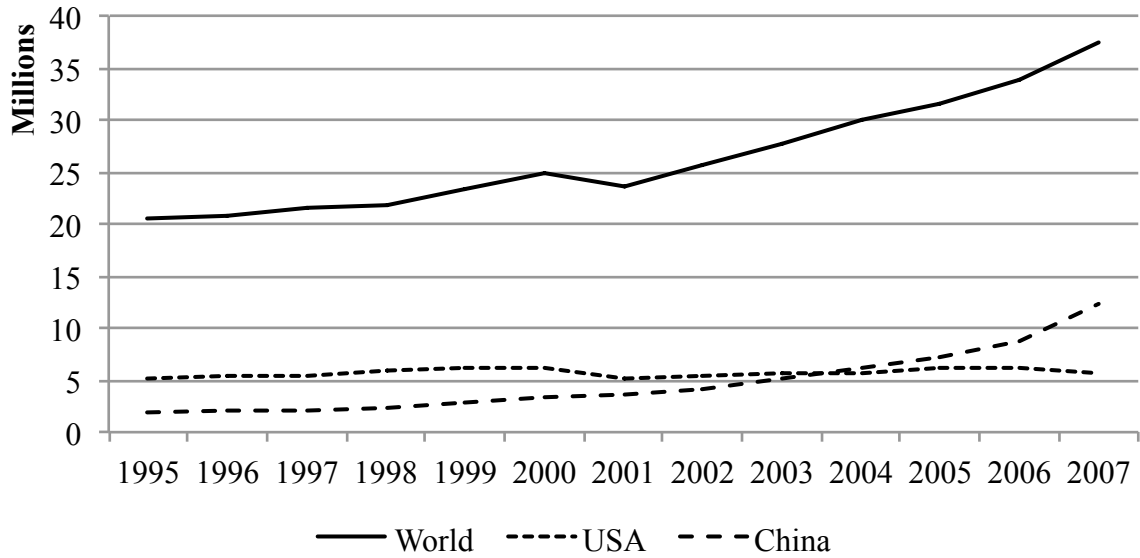


Figure 4: Yearly Aluminium Demand [mt]

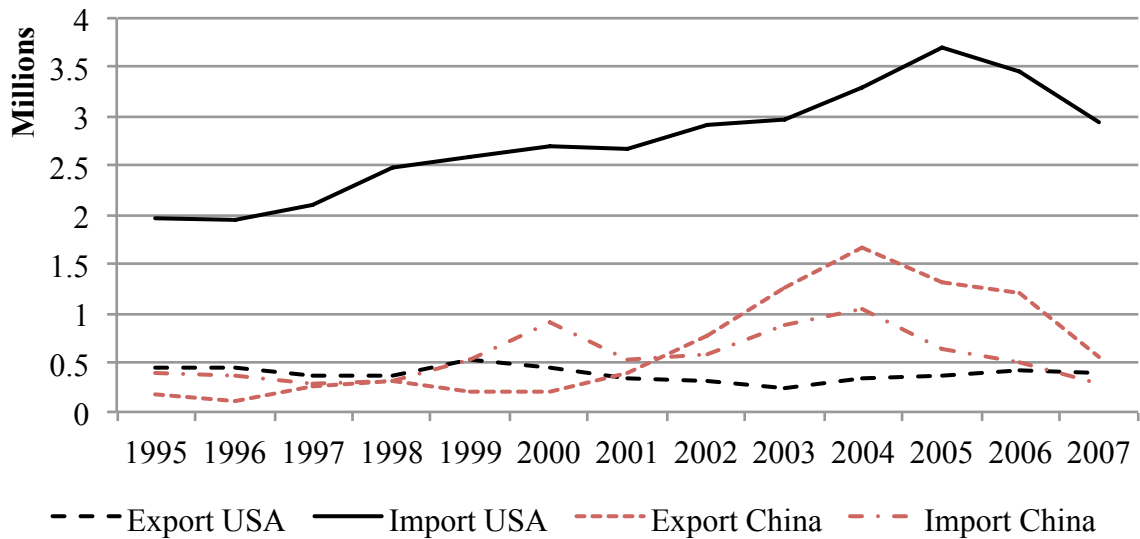


Figure 5: Yearly Aluminium Exports and Imports in China and the US [mt]

economy had a strong effect on world aluminium prices from the beginning of the collected data in 1987 up until 2008.

2 Model

The model builds on a standard DSGE framework with households, firms, a government and a monetary authority (see [Clarida et al. \(2001\)](#), [Galí \(2002\)](#)). Following [Unalmis et al. \(2012\)](#) and [Tumen et al. \(2015\)](#) works on oil storage, there is a competitive storer of aluminium, exogenous aluminium supply and aluminium is used in production, but not in consumption. The model of [Unalmis et al. \(2012\)](#) is extended by taking into account storage rigidities reflecting queues in aluminium warehouses. The price of aluminium is endogenously determined.

Households maximise their utility out of consumption and provide labour to firms against a wage. They own the firms they are working for and receive their dividends and they hold a capital stock and rent it out to firms in a perfectly competitive market. Firms produce a differentiated good using labour, capital and aluminium as input and are price setters in a sticky price framework. The competitive, risk-neutral and profit maximising storer buys and stores aluminium in one period and sells it in the next depending on the arbitrage conditions and cost of storage adjustment.

In the following, small letters denote percentage deviations from steady-state.

2.1 Households

The infinitely lived households, indexed by j , maximise their lifetime utility by choosing the level of consumption, $C_t(j)$, and labour supply, $N_t(j)$, according to:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t(j) - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t(j)^{1+\varphi}}{1+\varphi} \right].$$

H_t defines habit consumption: $H_t = hC_{t-1}$ with $h \in [0, 1]$ being the habit formation parameter. $\sigma > 0$ defines the inverse constant elasticity of substitution of consumption, $\varphi > 0$ is the inverse of the intertemporal elasticity of hours, and $\beta \in [0, 1]$ represents the discount factor in the model. Aggregation of the households consumption follows a constant elasticity of substitution (CES) aggregator:

$$C_t = \left(\int_0^1 C_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}},$$

with ϵ being the constant elasticity of substitution between varieties.

The households optimise their utility under the nominal budget restriction:

$$P_t C_t(j) + P_t I_t(j) + \mathbb{E}_t [Q_{t,t+1} D_{t+1}(j)] \leq D_t(j) + W_t N_t(j) + R_t^K K_t(j) + \Pi_t(j) + T_t(j).$$

The budget constraint implies on the income side that households have a portfolio $D_t(j)$ which pays out one unit of currency in a particular state, that they earn a wage, W_n , from their labour, $N_t(j)$, receive the rate of return on capital, R_t^K , on their invested capital stock, $K_t(j)$, receive the profits of monopolistic firms $\Pi_t(j)$ and the lump-sum transfer from government $T_t(j)$.³ On the expenditure side, households consume $P_t C_t(j)$ and invest $P_t I_t(j)$. Furthermore, $D_{t+1}(j)$ is the expected nominal pay off in the next period of the portfolio held at the end of the period and $Q_{t,t+1}$ is the stochastic discount factor for the one period ahead nominal pay off.

Inherent in the budget constraint is the decision of capital allocation. Households own firms and rent capital to them by deciding their investment level given capital adjustment cost. Capital accumulation follows the following dynamics:

$$K_{t+1}(j) = (1 - \delta)K_t(j) + \Phi\left(\frac{I_t(j)}{K_t(j)}\right) K_t(j), \quad (1)$$

with $\delta \in [0, 1]$ being the depreciation rate of the capital stock, $K_t(j)$, and $I_t(j)$ being the households investment. The model features capital adjustment cost, $\Phi\left(\frac{I_t(j)}{K_t(j)}\right)$, with their steady state values being $\Phi_{ss} = \delta$ and for their first and second derivatives, $\Phi'_{ss} = 1$, $\Phi''_{ss} = \xi < 0$ and $\delta\xi = -1$.

Assuming complete asset markets implies perfect risk-sharing among households. Therefore, we can drop the index j of households. The above described optimisation problem leads to the following optimality conditions:

$$(C_t - H_t)^\sigma N_t^\varphi = \frac{W_t}{P_t}, \quad (2)$$

$$\frac{1}{R_{t-1}} = \beta \frac{P_{t-1}}{P_t} \left(\frac{C_t - H_t}{C_{t-1} - H_{t-1}} \right)^{-\sigma}, \quad (3)$$

$$P_{t-1} \Lambda_{t-1} = \beta \frac{P_{t-1}}{P_t} \left(\frac{C_t - H_t}{C_{t-1} - H_{t-1}} \right)^{-\sigma} (R_t^K + P_t \Lambda_t \tilde{\Phi}), \quad (4)$$

³The lump sum transfer is set so that the government budget balances

with R_t being the risk free nominal interest rate, $\Lambda_t = \left[\Phi' \left(\frac{I_t}{K_t} \right) \right]^{-1}$ and $\tilde{\Phi} = \left[(1 - \delta) + \Phi \left(\frac{I_t}{K_t} \right) - \frac{I_t}{K_t} \Phi' \left(\frac{I_t}{K_t} \right) \right]$ being the shadow prices of capital.

2.2 Firms

The good is produced under monopolistic competition and used for consumption and investment. A continuum of firms produces a differentiated good indexed by i and given the constant elasticity of substitution production function:

$$Y_t(i) = A_{y,t} \left[(1 - w_{ly})^{\frac{1}{\rho_y}} V_t(i)^{\frac{\rho_y - 1}{\rho_y}} + w_{ly}^{\frac{1}{\rho_y}} L_{y,t}(i)^{\frac{\rho_y - 1}{\rho_y}} \right]^{\frac{\rho_y}{\rho_y - 1}}, \quad (5)$$

with $L_{y,t}(i)$ being the amount of aluminium used in the production of the core good and $V_t(i)$ being the value added input. $w_{ly} \in [0, 1]$ is the share of aluminium used in production and ρ_y is the elasticity of substitution between the two inputs. Furthermore, there is a total factor productivity shock, $A_{y,t}$, which equally affects all firms.

The value added input is produced by the firms using capital and labour and the CES production function:

$$V_t(i) = \left[(1 - w_{ny})^{\frac{1}{\rho_v}} K_t(i)^{\frac{\rho_v - 1}{\rho_v}} + w_{ny}^{\frac{1}{\rho_v}} (A_{n,t} N_t(i))^{\frac{\rho_v - 1}{\rho_v}} \right]^{\frac{\rho_v}{\rho_v - 1}}, \quad (6)$$

with ρ_v being the elasticity of substitution and $w_{ny} \in [0, 1]$ is the share of labour in production. Here, $A_{n,t}$ stands for a labour productivity shock. Firms take prices (including the endogenously determined price of aluminium, $P_{l,t}$) as given and minimise their costs:

$$\min_{L_{y,t}(i), K_t(i), N_t(i)} P_{l,t} L_{y,t}(i) + R_t^K K_t(i) + W_t N_t(i).$$

This leads to the following optimality conditions:

$$\frac{P_{l,t} L_{y,t}(i)^{\frac{1}{\rho_y}}}{w_{ly}^{\frac{1}{\rho_y}}} = \frac{R_t^K K_t(i)^{\frac{1}{\rho_v}}}{(1 - w_{ny})^{\frac{1}{\rho_v}} (1 - w_{ly})^{\frac{1}{\rho_y}}} = \frac{W_t N_t(i)^{\frac{1}{\rho_v}}}{A_{n,t}^{\frac{\rho_v - 1}{\rho_v}} w_{ny}^{\frac{1}{\rho_v}} (1 - w_{ly})^{\frac{1}{\rho_y}}}. \quad (7)$$

Given optimal allocation, the nominal marginal cost are:

$$MC_t^n = \frac{1}{A_{y,t}} \left[(1 - w_{ly}) V_{c,t}^{1-\rho_y} + w_{ly} P_{l,t}^{1-\rho_y} \right]^{\frac{1}{1-\rho_y}}, \quad (8)$$

with $V_{c,t}$ being the cost of the value added input, defined as:

$$V_{c,t} = \left[(1 - w_{ny}) R_t^K^{1-\rho_v} + w_{ny} \left(\frac{W_t}{A_{n,t}} \right)^{1-\rho_v} \right]^{\frac{1}{1-\rho_v}}. \quad (9)$$

Firms have price setting power but only a random fraction, θ , can reset their prices each period as laid out in the [Calvo \(1983\)](#) staggered price setting framework. Here, a partial indexation to past inflation is included. This leads to the following (log-linearised) Philipps curve:

$$\pi_t = \frac{\beta}{1 + \beta\varsigma} \mathbb{E}_t [\pi_{t+1}] + \frac{\varsigma}{1 + \beta\varsigma} \pi_{t-1} + \frac{(1 - \theta)(1 - \beta\theta)}{\theta(1 + \beta\varsigma)} mc_t, \quad (10)$$

with ς being the inflation indexation parameter and $\theta \in [0, 1]$ denoting the share of randomly selected firms which cannot adjust their prices optimally in each period. π_t is the CPI inflation and mc_t denotes the marginal cost.

2.3 Aluminium Storage

Aluminium storage refers to the physical storage of finished aluminium products, which can be used for production. Specific to the aluminium warehouses is that stock-outs are subject to queues and these queues were found to be manipulated by warehouse owners in order to influence prices as laid out in the report by the [US Senate Permanent Subcommittee on Investigations \(2014\)](#). The mechanism alluded to in the report is as follows: warehouse owners held inventory in their own warehouses and shifted these inventories between warehouses in order to cause queues, if this was in their interest.⁴ These queues lead to inventory levels having a relatively low volatility. There is a continuum of competitive

⁴When a warehouse owner intended to sell he would move aluminium between inventories, so that queues increased, less demand could be met and the aluminium price eventually increased.

storsers⁵ that maximise their profit⁶ from buying, storing and eventually selling aluminium:

$$\max_{S_t} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left[\frac{\alpha \mathbb{E}_t(P_{l,t+1}) S_t}{R_t} - P_{l,t} S_t \left(1 + \Upsilon(S_t) + \frac{\phi_s}{2} \left(\frac{S_t}{S_{t-1}} - 1 \right)^2 \right) \right],$$

with S_t being the inventory level, $\Upsilon(S_t) = \kappa + \frac{\Psi}{2} S_t$ representing the physical cost of storing one unit of aluminium. $\kappa < 0$ denotes the convenience yield⁷ or relative benefit of holding the physical asset over time and $\Psi > 0$ represents the increasing costs with the quantity stored. Furthermore, there is a loss of inventory $(1 - \alpha) \in [0, 1]$ over time. Inventories can only be positive and here this constraint is implemented by having a sufficiently high steady state inventory level compared to the deviations. Another approach would be to incorporate non-linearities but for simplicity this approach is not chosen here.⁸

This modelling approach draws on the work by [Unalmis et al. \(2012\)](#) and here I extend it by adding adjustment cost, reflecting the stickyness of inventory levels. The parameter, ϕ_s , denotes the quadratic adjustment cost of inventory levels (cf. [Rotemberg \(1982\)](#)).

Storsers are price takers in the aluminium market and their first order condition with respect to S_t is:

$$\frac{\alpha}{R_t} = \frac{P_{l,t}}{P_{l,t+1}} \left(1 + \kappa + \Psi S_t + \frac{\phi_s}{2} \left(\frac{S_t}{S_{t-1}} - 1 \right)^2 + \frac{S_t}{S_{t-1}} \phi_s \left(\frac{S_t}{S_{t-1}} - 1 \right) \right) - \left(\frac{S_{t+1}}{S_t} \right)^2 \beta \phi_s \left(\frac{S_{t+1}}{S_t} - 1 \right)$$

In log-linearised form this becomes:

$$\mathbb{E}_t [\hat{p}_{l,t+1} + \pi_{t+1}] - r_t = \hat{p}_{l,t} + \frac{1}{\Theta} s_t + \frac{\phi_s}{\alpha\beta} (s_t - s_{t-1}) - \frac{\phi_s}{\alpha} (\mathbb{E}_t [s_{t+1}] - s_t) + a_{s,t}, \quad (11)$$

with $\Theta = \frac{\alpha\beta}{\alpha\beta - 1 - \kappa}$, $\hat{p}_l = p_l - p$ denoting the real price of aluminium and $a_{s,t}$ being an exogenous storage demand shock following a stochastic stationary process. Therefore, the decision on storage levels depends on past and future expected storage levels as well as current and expected aluminium price levels, the interest rate and an exogenous shock.

⁵The competitive storsers have the same rational expectations. Therefore, no indexation is needed.

⁶The profits of the competitive storsers is distributed to the households via the lump sum transfer, T_t .

⁷The convenience yield is a commonly assumed feature of commodities markets and [Figuerola-Ferretti and Gonzalo \(2010\)](#) estimate it for the aluminium market.

⁸For a discussion on modelling non-linearities in DSGE models see e.g. [Fernández-Villaverde et al. \(2015\)](#) for the case of the zero lower bound on interest rates.

2.4 Goods markets equilibrium

The goods markets always clear in equilibrium and satisfy the condition:

$$Y_t(i) = G_t(i) + I_t(i) + C_t(i), \quad (12)$$

with $G_t(i)$ being the government demand.

Furthermore, the market for aluminium is always in equilibrium. That implies that the world endowment of aluminium, $L_{s,t}$, plus old inventories less depreciation, equals the use in production and new inventories:

$$L_{y,t} + S_t = L_{s,t} + \alpha S_{t-1}, \quad (13)$$

with, $L_{s,t}$, being subject to an exogenous shock defined by a stationary AR(1) process.

2.5 Monetary Policy

Monetary policy follows a Taylor rule:

$$r_t = \phi_r r_{t-1} + (1 - \phi_r) \phi_\pi \pi_t + (1 - \phi_r) \phi_y y_t, \quad (14)$$

with $\phi_r \in [0, 1]$ denoting the interest rate smoothing and ϕ_y, ϕ_π being the monetary policy response to inflation and output.

2.6 Fiscal Policy

Government demand is directed towards the core good only:

$$G_t = \left(\int_0^1 G_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}.$$

The public sector does not have a deficit in our model and therefore the demand equals a lump-sum tax:

$$P_t T_t = G_t.$$

Under optimal allocation this yields the government demand function:

$$G_t(i) = \left(\frac{P_t}{P_t(i)} \right)^\epsilon G_t,$$

with the process for government spending, G_t , being a stationary AR(1) process.

3 Estimation

I estimate two versions of the model, one without storage and one with storage and storage adjustment cost. The models are estimated in their respective log-linearised approximations. In a subsequent step each model is transformed into a state-space representation and the likelihood is evaluated with a Kalman filter. Given the prior distributions of the parameters, as described in 4.2, and the likelihood we obtain the posterior densities of the parameters. Ultimately, a Markov Chain Monte Carlo simulation is used to maximise the posterior density.⁹

3.1 Data

The model is estimated on U.S. data from 1987Q1 until 2008Q2 using quarterly data of output, investment, CPI inflation, interest rate, aluminium price and aluminium storage levels. The time frame used for estimation spans 1987 until 2008, following the findings of Galí et al. (2012), Lubik and Schorfheide (2004). The latter show that DSGE models are indeterminate before 1982 due to a shift in monetary policy and the former argues that the zero lower bound leads to non-linearities, which cannot be captured with a linear model. The monthly time series of aluminium prices and aluminium storage levels, provided by the U.S. Geological Survey, are first deseasonalised using the X13-ARIMA-SEATS procedure and then converted to a quarterly frequency. Aluminium prices are deflated using the CPI index. Aluminium storage levels are converted to a per capita basis using the civilian non-institutional population time series. The same per capita transformation is undertaken for investment (Gross Fixed Capital Formation), with investment being deflated by the GDP deflator. The federal funds rate and real GDP per capita are taken directly from

⁹The Dynare 4.4.3 software is used for the estimation. The Metropolis-Hastings algorithm finds the posterior density based on 250.000 draws.

the Federal Reserve Bank of St. Louis' database (FRED), as are all other time series not related to aluminium. Finally, the time series for real GDP per capita, real investment per capita, CPI inflation, federal funds rate, real price of aluminium and aluminium storage per capita are then transformed into the log-difference from the Hodrick-Prescott filtered trend ($\lambda = 1600$).

3.2 Calibrated Parameters

Since the model is based on a standard DSGE framework we can draw on a large literature regarding parameter calibration. As usual for this type of models we set capital depreciation, $\delta = 0.025$, $\beta = 0.99$, implying a riskless rate of return of 4% and the investment and government share of output are set to $I_g = 0.2$ and $G_g = 0.18$. The labour share in the production of the value added input V_t is set to $w_{ny} = 0.66$ following the results of [Rios-Rull and Santaaulalia-Llopis \(2010\)](#) and [Raurich et al. \(2012\)](#). Regarding the aluminium parameters we calculate the share of aluminium in output¹⁰ to be $w_{ly} = 0.0038$ and the ratio of storage to supply in steady state to be $L_s^{ss} = 0.9$.¹¹

4 Results

The model with storage but without adjustment cost, failed to identify the shock variance for storage demand. This is evidence for it being a misspecified model and only the addition of storage adjustment cost helped reconcile it with the data.

4.1 Calibrated Parameters

Not all parameter values can be estimated in our model and some need to be fixed relying on microevidence or simply draw on evidence from other studies who estimated such models for the US economy. These variables include the discount facotr $\beta = 0.99$ ¹², the depreciation rate $\delta = 0.025$, the share of investment spending in output $I_y = 0.2$, the share of government spending in output $G_y = 0.18$, and the share of labour in the value added

¹⁰The share is calculated using BAE input output tables for the US economy in 2007.

¹¹I take the average storage to supply ratio before the structural drop around 2000.

¹²A value of 0.99 implies a yearly riskless return of 4%.

product $w_{ny} = 0.66$. These values are standard in the literature for models calibrated on the US economy (see

4.2 Prior and Posterior Distributions

The model is taken to the data (output, investment, CPI inflation, interest rate, aluminium price and aluminium storage levels) to estimate 12 structural parameters, and the AR(1) coefficients and shock standard deviations for the six shocks (aluminium supply, labour productivity, total factor productivity, government spending, monetary policy, and storage demand shock). The model without storage is estimated on output, investment, CPI inflation, interest rate and the aluminium price, does not have the storage demand shock and has 10 structural parameters to estimate.

Table 1 shows the results of the parameter estimation. The priors of the staggered price parameters, consumer preferences and the monetary policy block are taken from the results of [Sahuc and Smets \(2008\)](#) and [Nakov and Pescatori \(2010\)](#). The calvo probability, θ , and the price indexation parameter, ς , have a beta prior with mean 0.5 and standard deviation 0.15. Regarding consumer preferences, the consumption utility parameter, σ , has a normal prior with mean 1 and standard deviation 0.1 and the inverse Frisch labor supply elasticity has a gamma distribution prior with mean 1 and standard deviation 0.25. The prior of the habit formation, h , follows a beta distribution with mean 0.6 and standard deviation 0.1. Turning to the monetary policy block, the interest rate smoothing parameter, ϕ_r , has a beta prior with mean 0.6 and standard deviation 0.1, the inflation and output gap parameters, ϕ_π and ϕ_y have a gamma prior with mean 1.5 and 0.5 and standard deviations 0.5 and 0.15 respectively. The priors for all standard deviations of the exogenous shocks follow an inverse gamma distribution with mean 2 and standard deviation 2. The persistence parameters of the exogenous shocks follow a beta distribution with mean 0.5 and standard deviation 0.2.

Finally, the parameters specific to our model with aluminium are defined. The convenience yield, κ , is suspected to be negative but we allow the data to tell us otherwise by setting a normal prior with mean -0.03 and standard deviation 0.1. The degree of storage level stickiness governed by, ϕ_s , has a normal prior with mean 0 and standard deviation 0.5. Finally, the elasticity of substitution for labour and aluminium, ρ_v and ρ_y , have a gamma

Parameters		Prior Mean	Posterior Distribution			Prior	Prior SD
			Mean	90% HPD Interval			
Persistence of exogenous processes							
ρ_g	Government Spending	0.500	0.7762	0.6946	0.8601	beta	0.2000
ρ_{ay}	Total Factor Prod.	0.500	0.8006	0.6982	0.8808	beta	0.2000
ρ_{an}	Labour Productivity	0.500	0.9153	0.8848	0.9463	beta	0.2000
ρ_{mp}	Monetary Policy	0.500	0.5993	0.4915	0.7086	beta	0.2000
ρ_l	Aluminium Supply	0.500	0.1208	0.0236	0.2132	beta	0.2000
ρ_{as}	Storage Demand	0.500	0.7727	0.6941	0.8538	beta	0.2000
Structural Parameters							
ρ_y	Elasticity: Aluminium/VA	5.000	3.6120	1.7253	5.4485	gamma	2.0000
ρ_v	Elasticity: Capital/Labour	0.100	0.4094	0.2468	0.5793	gamma	0.0500
ϕ_s	Inventory level adj. cost	1.000	0.4623	0.2938	0.6284	gamma	0.2500
κ	Convenience yield	-0.030	-0.0215	-0.0237	-0.0199	norm	0.0500
θ	Calvo Parameter	0.500	0.7291	0.6797	0.7819	beta	0.1500
ς	Price indexation	0.500	0.3795	0.1957	0.5611	beta	0.1500
h	Habit persistence	0.600	0.2512	0.1326	0.3657	beta	0.1000
σ	inv. el. of int.subst. cons.	1.000	0.7284	0.5170	0.9142	norm	0.1000
φ	inv. el. of labor supply	1.000	0.8846	0.4873	1.2595	gamma	0.2500
ϕ_π	Int. rate: inf. response	1.500	4.7996	3.7491	5.8215	gamma	0.5000
ϕ_y	Int. rate: output response	0.500	0.4921	0.4121	0.5728	gamma	0.0500
ϕ_r	Int. rate: persistence	0.600	0.5662	0.4737	0.6620	beta	0.1000
Standard Deviation of Shocks							
ε_g	Government Spending	2.000	2.7188	1.8951	3.7420	invg	2.0000
ε_{ay}	Total Factor Prod.	2.000	0.5632	0.4668	0.6562	invg	2.0000
ε_{an}	Labour Productivity	2.000	0.4650	0.3681	0.5589	invg	2.0000
ε_r	Monetary Policy	2.000	0.3854	0.3146	0.4438	invg	2.0000
ε_l	Aluminium Supply	2.000	2.6726	2.3250	3.0066	invg	2.0000
ε_{as}	Storage Demand	2.000	1.6380	1.0128	2.2575	invg	2.0000

Table 1: Prior distributions and posterior estimates - full sample

distribution prior with mean 0.4 and standard deviation 0.1.

4.3 Variance Decomposition

Variance decomposition allows the identification of each shocks importance for the variable in question. Table 2 shows the relative importance of the structural shocks in explaining the variance of model variables. The aluminium price volatility is mainly explained by the storage demand shock and partially by aluminum supply and labour supply shocks. Storage itself is mainly driven by aluminium supply and much less so by storage demand. There is only a weak influence of real demand variables on the aluminium market and a

	ε_r	ε_g	ε_l	ε_{ay}	ε_{an}	ε_{as}
y	0.01	0.06	0.03	3.38	94.69	1.83
c	0.00	1.07	0.02	2.23	95.50	1.17
i	0.00	0.01	0.00	0.09	99.74	0.15
r	0.11	1.94	0.00	1.39	96.39	0.17
π	7.32	1.71	0.00	1.90	88.72	0.35
l_y	0.00	0.00	1.20	0.00	0.20	98.59
\hat{p}_l	0.00	0.00	1.20	0.00	0.17	98.62
s	0.00	0.00	35.36	0.00	0.01	64.64

Table 2: Variance Decomposition (%) - full sample

Quarter		ε_r	ε_g	ε_l	ε_{ay}	ε_{an}	ε_{as}
y	4	10.15	9.95	0.00	50.08	29.35	0.46
	6	8.60	8.97	0.00	49.21	32.76	0.46
	12	7.26	7.88	0.00	45.51	38.93	0.42
	50	6.77	7.37	0.00	42.75	42.71	0.39
s	4	0.00	0.00	99.67	0.00	0.00	0.33
	6	0.00	0.00	99.50	0.00	0.00	0.50
	12	0.00	0.00	99.11	0.00	0.00	0.88
	50	0.00	0.01	98.56	0.00	0.01	1.42
\hat{p}_l	4	0.05	0.35	1.92	0.41	0.03	97.23
	6	0.05	0.34	1.73	0.44	0.07	97.37
	12	0.05	0.33	1.62	0.48	0.20	97.32
	50	0.05	0.33	1.63	0.49	0.36	97.14

Table 3: Conditional Variance Decomposition (%) - full sample

weak but non-negligible influence of the aluminum market on the US economy.

Table 3 shows the conditional variance decomposition over different time horizons. For example, storage demand explains more of the short term (4 quarters) rather than the long term (50 quarter) variation in output. On the contrary, storage demand shocks explain less of the short term variation in storage compared to the long term.

The following two figures explain the variance of real aluminium prices for the full sample period. Figure 6 shows the result for the model without storage. Most of the price variance is attributed to changes in supply, but a significant part can be assigned to labour productivity shocks, especially in the mid 1990s.

The following variables are to be understood as percentage deviations from steady-state: y - real output, c real consumption, i real investment, r - interest rate, pi - inflation, p_rl - real price of aluminium, l_y - aluminium in production.

The results for the model with storage and storage adjustment cost are very different. Figure 7 shows that storage demand shocks were the dominant determinant throughout the sample.¹³ Supply shocks still played a role but a significantly lesser one. Apart from these two price determinants, labour productivity shocks and TFP shocks played a minor role. The strong influence of aluminium supply hints at the influence of the model setup on the estimation results. Demand side factors in the US economy are estimated as less relevant for the aluminium market. An open economy model would certainly attribute some of the variation to foreign demand, especially China in the case of aluminium. Unalmis et al. (2012) noted a similar difference in results for their closed economy model including oil compared to the open economy model by Bodenstein et al. (2011). Whereas the former find that productivity shocks are the main driver of oil price fluctuations in their closed economy model, the latter find that foreign productivity shocks and oil efficiency shocks drive oil prices in their open economy setup. Here we focus on the US economy and therefore the model attributes most of the unexplained variation to supply shocks. When adding storage and storage adjustment costs, the role of US demand further diminishes but the model clearly identifies a stronger influence of storage demand shocks compared to aluminium supply shocks.

This finding is in line with prior research, which showed that omitting storage leads to an over estimation of demand side factors (Unalmis et al., 2012).

4.4 Impulse Response Functions

Impulse response functions (IRF) allow the analysis of the impact of structural shocks to variables in the model. In the following I will interpret the results for Bayesian impulse response functions for all the relevant shocks in the model. The thick line represents the mode and the thin lines the lower and upper bounds of a 90% highest posterior density interval.

¹³The variables in the figures are to be interpreted as follows: p_rl real price of aluminium, e_l aluminium supply shock, e_an labour productivity shock, e_ay total factor productivity shock, e_g government spending shock, e_r monetary policy shock, e_as storage demand shock.

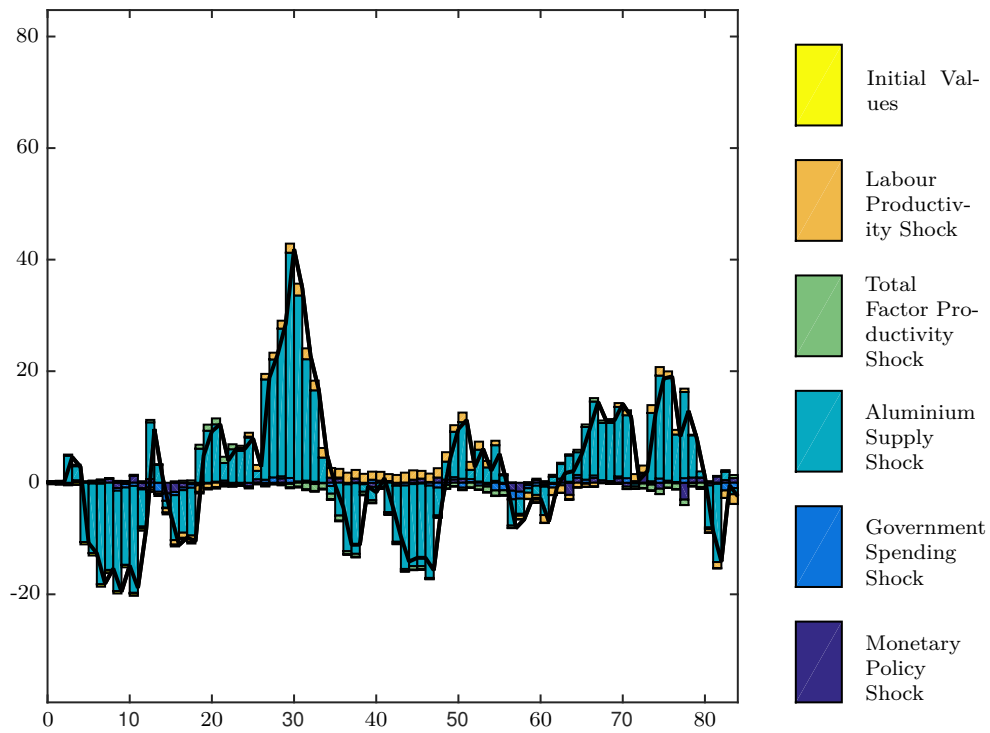


Figure 6: Shock decomposition for p_{rl} - Model without storage.

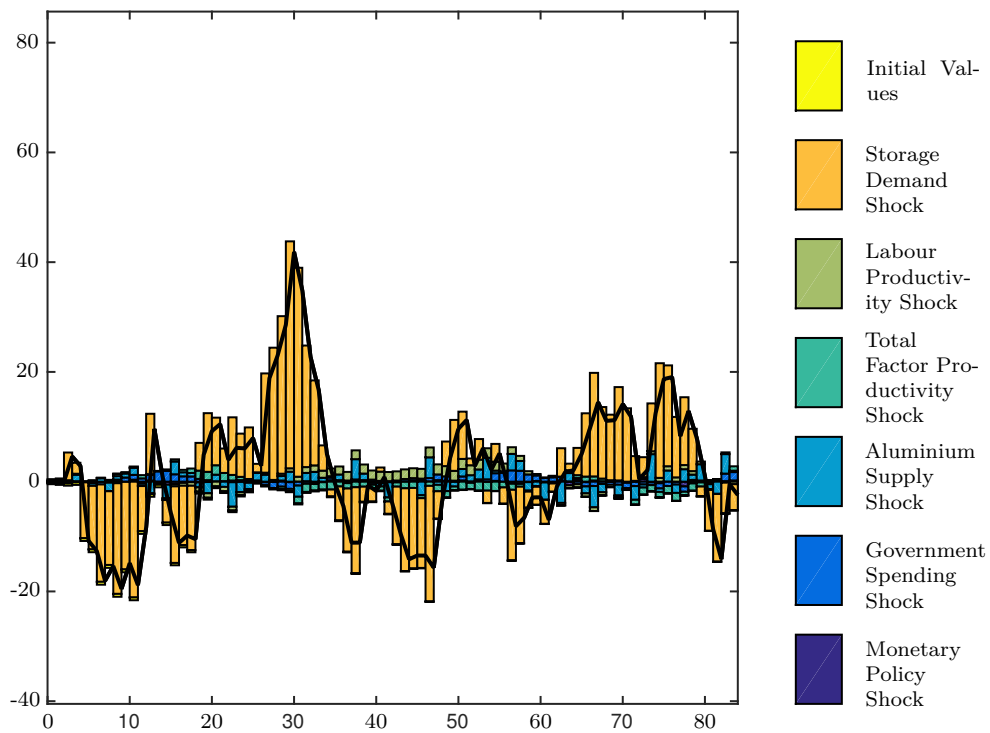


Figure 7: Shock decomposition for p_{rl} - Model with storage and storage adjustment cost.

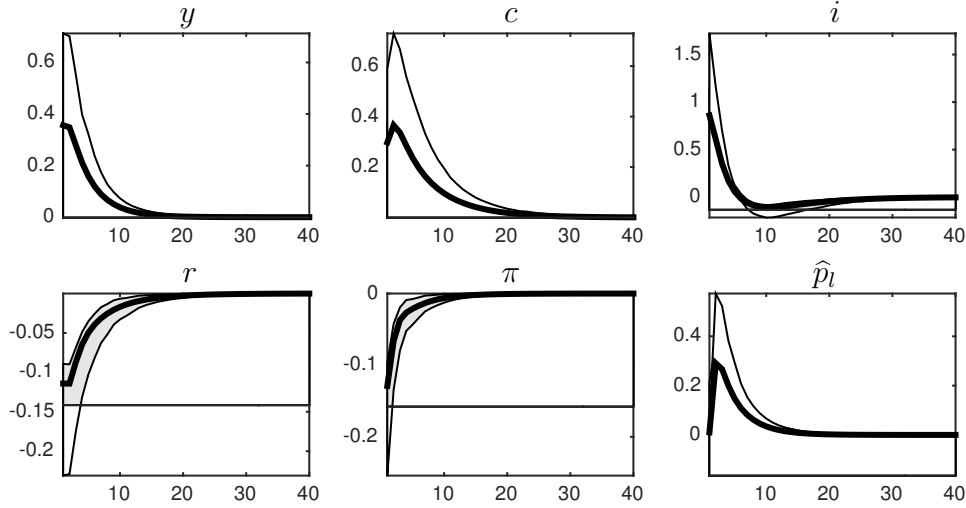


Figure 8: IRF - model without storage (orthogonalized shock to e_{ay}).

4.4.1 Total factor productivity shock

Figure 8 shows the response over 40 quarters to a one standard deviation total factor productivity (TFP) shock in the model without storage.¹⁴ Demand for all factors increases and the supply of aluminium is fixed, which leads to a price increase for aluminium. The increased factor productivity leads to lower prices, to which monetary policy reacts by lowering nominal interest rates. The fall in prices is smaller than the fall in the nominal interest rate, leading to a decrease in the real interest rate.

The reaction to a one standard deviation positive TFP shock in the extended model (storage and storage adjustment costs) is broadly similar. The additional storage component reacts to the lower real interest rate with an increase in storage levels. This additional storage demand leads to an even more pronounced price increase for aluminium. The increase in storage levels is very persistent, which is coherent with the relatively high storage adjustment costs ($\phi_s = 0.52$).

A one standard deviation positive TFP shock leads to, higher aluminium prices, output and storage levels. Inflation and real interest rates decrease as a response to the shock.

¹⁴The variables in the figures are to be interpreted as log deviations from steady state for: p_{rl} real price of aluminium, π CPI inflation, c consumption, i investment, y output, r nominal interest rate, s inventories, l_y aluminium used in production. The applied shocks are: e_{ay} total factor productivity shock, e_l aluminium supply shock, e_{an} labour productivity shock, e_g government spending shock, e_r monetary policy shock, e_{as} storage demand shock.

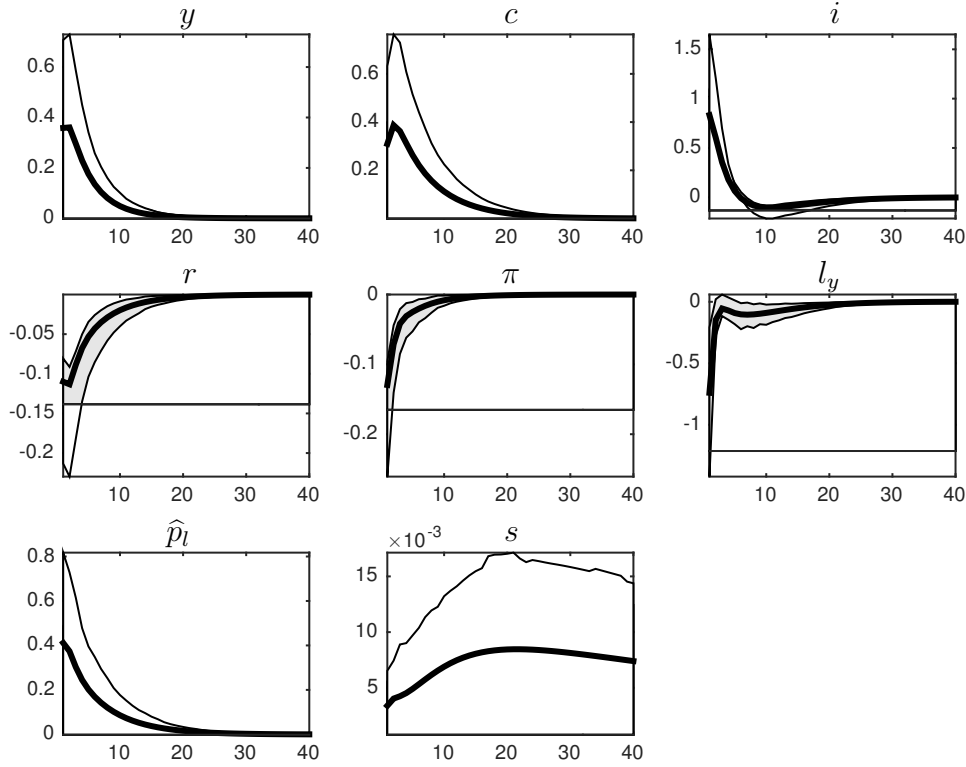


Figure 9: IRF - model with storage and storage adjustment cost (orthogonalized shock to e_{ay}).

4.4.2 Labour productivity shock

For a one standard deviation positive shock to labour productivity, Figure 10 shows the impulse response functions for the extended model (storage and storage adjustment cost). The results do not differ substantially for the variables excluding storage. Given a one standard deviation positive labour productivity shock, labour used in production decreases and is substituted by aluminium and capital. With the relatively high estimate for the elasticity of substitution, capital and aluminium increase significantly in production. The productivity gains are lower than in the case of the TFP shock, yet they lead to negative inflation and substantially higher output. The negative inflation and higher output are conflicting signals for the monetary authority, which initially marginally raises the nominal interest rate to lower it immediately after. The real interest rate remains above steady state and storage levels decrease as a reaction to the higher real interest rate. The decrease in storage demand puts downward pressure on aluminium prices but the heightened demand from aluminium demand for production dominates and leads to higher prices.

A one standard deviation positive labour productivity shock leads to higher output and

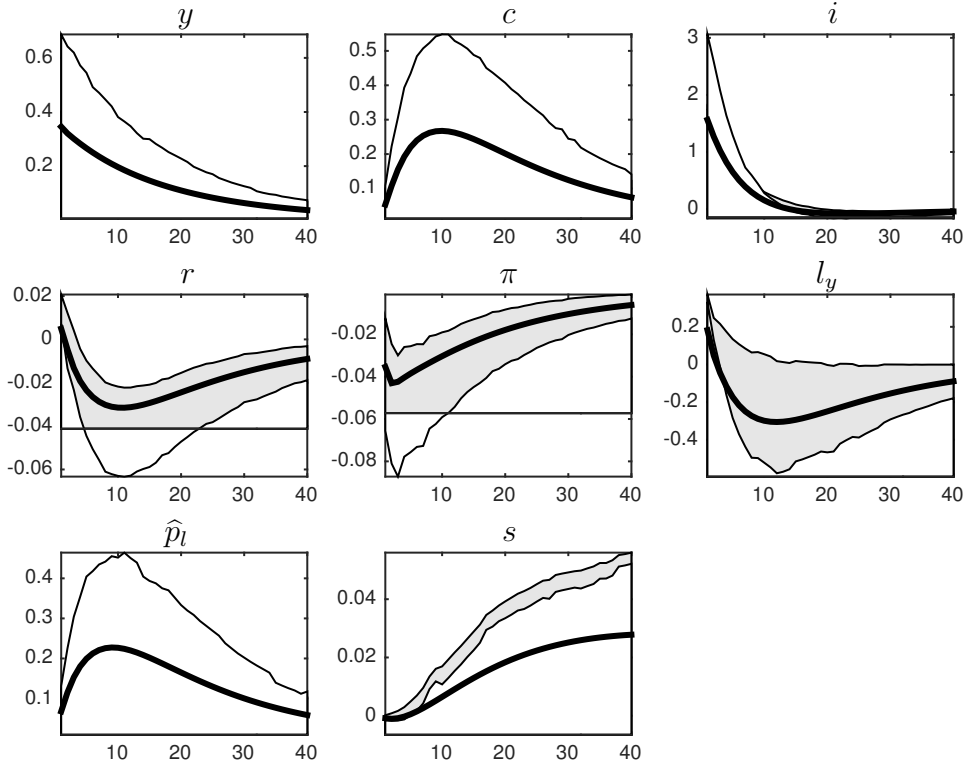


Figure 10: IRF - model with storage and storage adjustment cost (orthogonalized shock to e_{an}).

factor demand for aluminium and capital. At the same time aluminium prices increase and inflation decreases due to the productivity gains. Storage levels decrease as a reaction to the initially higher nominal interest rate.

4.4.3 Monetary Policy shock

A one standard deviation positive shock to interest rates leads to a steep fall in demand and a drop in aluminium prices and inflation. The negative demand shock leads to a fall in inflation, to which the monetary authority reacts by lowering the nominal interest rate. The fall in output affects factor demand and thereby aluminium used in production. The expected rebound of aluminium prices outweighs the increased cost for financing inventories and storage adjustment costs, so that aluminium storage increases marginally in response to a nominal interest rate shock.

Thereby, a monetary policy shock has an additional channel of influencing inflation through the price of aluminium. This finding is confirmed in [Blanchard and Gali \(2009\)](#) and [Blanchard and Riggi \(2013\)](#), which highlight the importance of oil price shocks for

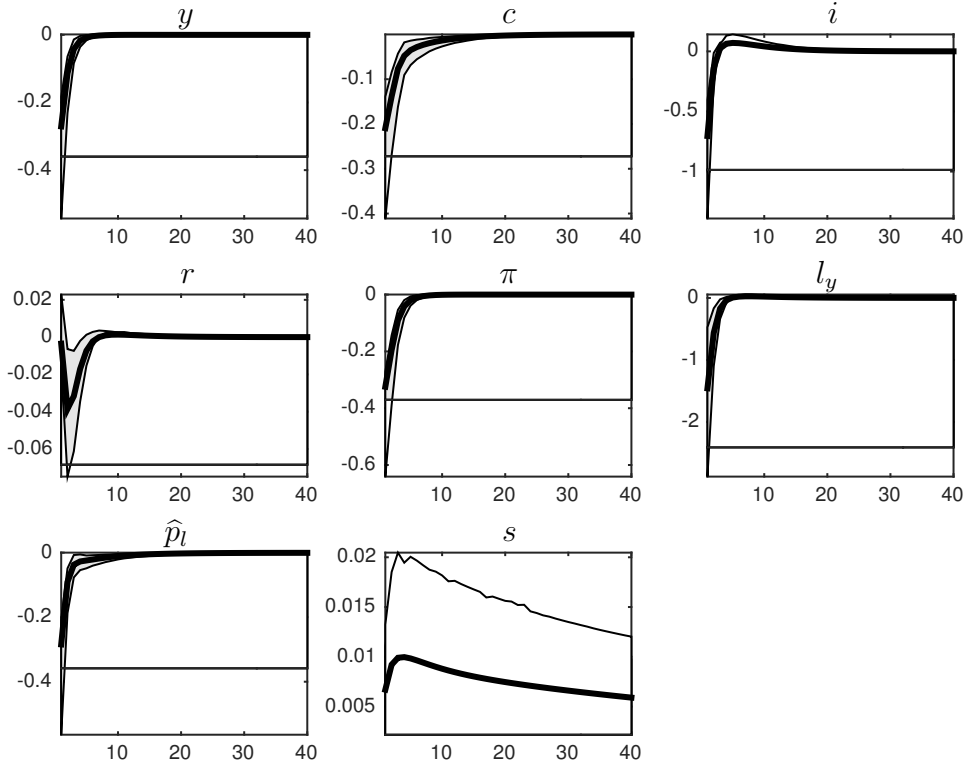


Figure 11: IRF - model with storage and storage adjustment cost (orthogonalized shock to e_r).

monetary policy and inflation dynamics. An interest rate shock leads to lower output, inflation and aluminium prices but increased storage levels.

4.4.4 Aluminium supply shock

A one standard deviation positive shock to aluminium supply differs for the two different models. Figure 12 shows the impulse responses for the model without storage. The increase in aluminium supply leads to a substantial decrease in the price of aluminium for supply reasons. From the demand side, the factor productivity rises and output and aluminium used in production increase. Due to the increase in factor productivity, the CPI inflation falls and the monetary authority lowers nominal interest rates. The real interest rate rises as a result of the change in inflation and the nominal interest rate.

The inclusion of storage leads to a very different dynamic for an aluminium supply shock, Figure 13. The additional supply is partially absorbed in storage because the expected rise in real aluminium prices outweighs the higher opportunity costs (real interest rate). Even with the increased storage demand the excess supply leads to a significant drop in

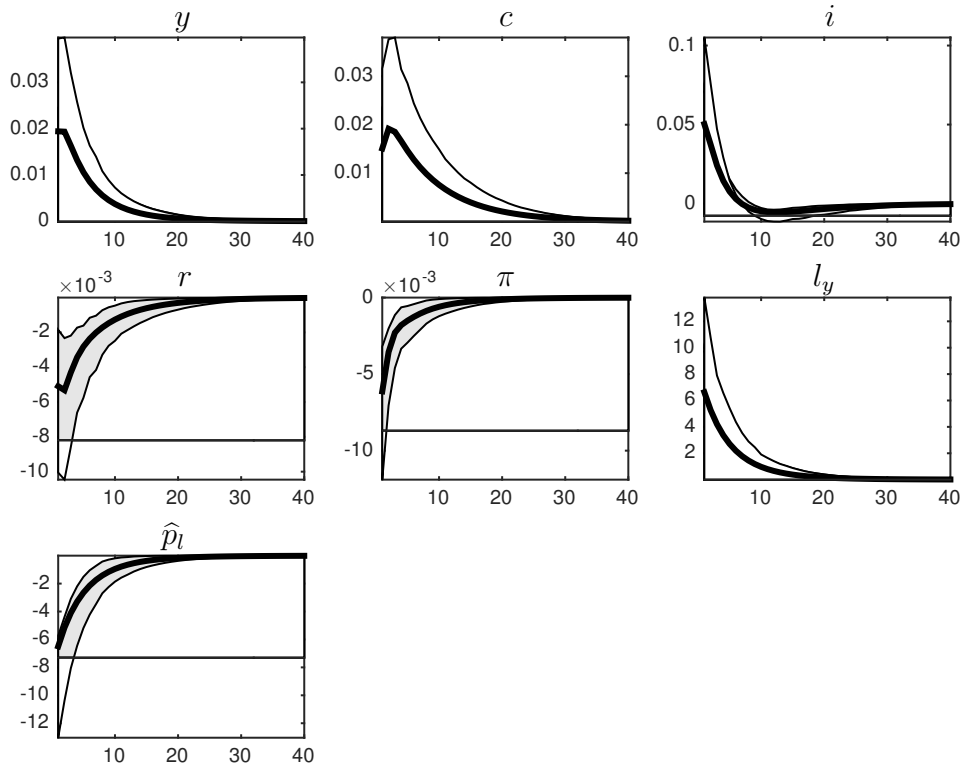


Figure 12: IRF - model without storage (orthogonalized shock to e_l).

aluminium prices. Regarding output and aluminium used in production the same logic holds as laid out above.

A one standard deviation positive aluminium supply shock has a strong negative impact on aluminium prices and a positive impact on storage levels. Inflation falls, together with the nominal interest rate, whereas output and aluminium used in production rise in response to an aluminium supply shock.

4.4.5 Storage demand shock

Figure 14 shows the impulse responses to a one standard deviation positive storage demand shock. This shock has the strongest effect on aluminium prices. A storage demand shock leads to less available aluminium for production. The decrease in available aluminium for the real economy implies the opposite reaction as for the aluminium supply shock. Output and aluminium used in production decrease. The lower output implies higher factor costs and thereby inflation, to which the monetary authority reacts by increasing nominal interest rates. Real interest rates are below zero and act as a positive reinforcement for storage levels.

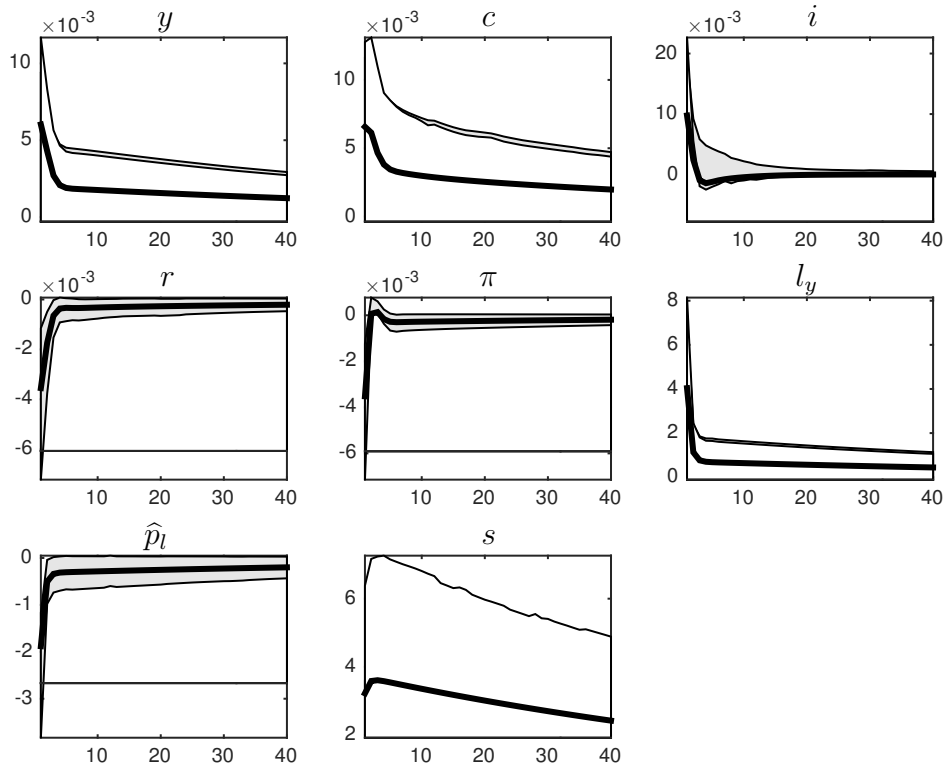


Figure 13: IRF - model with storage and storage adjustment cost (orthogonalized shock to e_l).

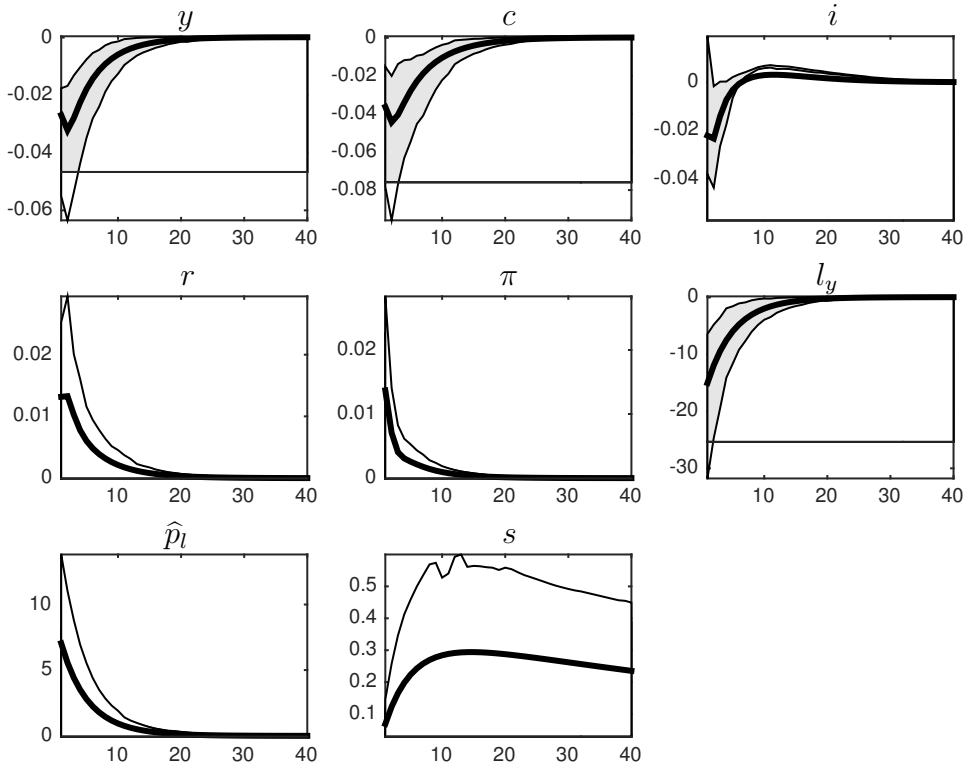


Figure 14: IRF - model with storage and storage adjustment cost (orthogonalized shock to e_{as}).

Key takeaways from the impulse response function are that high aluminium prices need not always be associated with low economic growth. This was highlighted by the reaction to TFP and labour productivity shocks. Furthermore, aluminium storage reacts to the real interest rate. Thereby, monetary policy has an additional channel by which it influences the real economy.

5 Conclusion

This paper is the first to investigate the effect of financialisation on the market for aluminium using a structural macroeconomic model. The hypothesis tested here is that financialisation, investment in commodity linked financial products, led to banks becoming an integral part of the aluminium market. In a second step they used their new found market power to manipulate prices by signalling demand via warehouse queues ([US Senate Permanent Subcommittee on Investigations, 2014](#)). Therefore, a storage demand shock, orthogonal to all other supply and demand shocks, can identify the demand due to speculative motives. Furthermore, the identification of a friction in inventory levels lends evidence to the influence of warehouse queues on price dynamics. Other works have investigated the market for oil using structural models (e.g. [Kilian \(2009\)](#)) but found no evidence of speculative demand. [Unalmis et al. \(2012\)](#) comes closest to the model used here. They investigate the oil market with a model including storage but equally find no major influence of speculative demand. The investigation with my model finds that both, the storage demand shock and the parameter representing the queues turn out to play a significant role and hint at the influence financialisation had on the aluminium market. This result warrants further investigation, because the demand side is modelled as a closed economy and storage demand can be interpreted as a precautionary demand shock. Nonetheless, the magnitude of the influence provides support to the hypothesis that financialisation had an impact on price dynamics. Furthermore, the presence of storage opens a secondary channel for monetary policy. An interest rate shock influences inflation additionally through aluminium prices. Last but not least, storage demand has a negative impact on the economy and therefore calls for policy makers to increase scrutiny of the queueing mechanism and inventory level transparency

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