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Macroeconomic resilience in a DSGE model

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Abstract in English

We use the dynamic stochastic general equilibrium (DSGE) model of Altig et al. (2005) to analyse the resilience of an economy in the face of external shocks. The term resilience refers to the ability of an economy to propser in the face of shocks. The Altig et al. model was chosen because it combined both demand and supply shocks and because various market rigidities/imperfections, which have the potential to affect resilience, are modelled. We consider the level of expected discounted utility to be the relevant measure of resilience. The effect of market rigidities, eg. wage and price stickiness, on the expected level of utility is minimal. The effect on utility is especially small when compared to the effect of market competition, because the latter has a direct effect on the level of output. This conclusion holds for the family of constant relative risk aversion over consumption utility functions. A similar conclusion was drawn by Lucas (1987) regarding the costs of business cycles. We refer to the literature that followed Lucas for ideas for how a DSGE model might be adjusted to give a more meaningful analysis of resilience. We conclude that the Altig et al. DSGE model does not produce a relationship between rigidities and the level of output and, hence, does not capture the effect of inflexibility on utility that one observes colloquially.

Keywords: Resilience, Nominal Rigidities, Capital Adjustment Costs, DSGE Models.

Abstract in Dutch

In dit paper analyseren wij de resilience van de Nederlandse economie. Het begrip resilience refereert aan het aanpassingsvermogen van een economie onderhavig aan een externe schok. Voor deze analyse gebruiken wij het dynamische stochastische algemeen evenwichtsmodel van Altig et al.(2005). Dit model biedt de mogelijkheid om vraag- en aanbodschokken te simuleren en een verscheidenheid aan marktrigiditeiten en imperfecties te onderzoeken op hun effect op de resilience van een economie. Als relatieve maat voor de resilience beschouwen wij de verwachte waarde van het verdisconteerde nut. Het effect van marktrigiditeiten, bijv. in het loon of in de prijs, op deze verwachte waarde is minimaal. Deze effecten zijn zeker beperkt als wij hen vergelijken met het effect van concurrentie op resilience, dat een direct effect heeft op het niveau van de productie. Deze conclusie geldt onder voorbehoud van een constante relatieve risicoaverse nutsfunctie over consumptie. Lucas (1987) trekt een vergelijkbare conclusie voor de kosten van een business cycle. Op basis van dit paper en de afgeleide literatuur presenteren wij ideeën om het DSGE model uit te breiden voor een uitgebreidere analyse van resilience. Wij concluderen dat het DSGE model van Altig et al. geen directe relatie oplevert tussen de rigiditeiten en het productieniveau, waardoor het bekende effect van inflexibiliteit op het nut onder deze rigiditeiten niet kan worden gereproduceerd.

Contents

Summary

Whilst resilience is a commonly heard expression in policy discussions, there is no universally accepted definition. With regards to the macroeconomy we often think of a resilient economy as one that remains close to potential output in an international environment that is changing rapidly or is subject to shocks, such as high oil prices. Our working definition of a resilient economy is an economy in which the level of expected discounted utility is not lowered by a given series of shocks. The focus on utility ensures that our conclusions are based on the welfare of individual agents, not on things like output volatility that may not be of concern to agents per se. We discuss four key issues with regards resilience: the definition of shocks; candidate definitions of resilience from the literature; the mechanisms involved in transmitting shocks to the real economy; and finally, the effect of shocks on welfare.

Our central question is whether price rigidity, wage rigidity and capital adjustment affect utility levels in the face of unexpected shocks. In light of the recent developments in macro modelling we use the model of Altig et al. (2005) to analyse the effects of variations in price flexibility, wage flexibility and capital adjustment costs on the level of utility in the face of demand and supply shocks.

The Altig et al. model is a micro-founded dynamic stochastic general equilibrium model calibrated to the US economy. That is, the model of the macroeconomy is built up from maximising agents, whereby households maximise utility and firms maximise profits. Therefore, the characteristics of the model can be traced back to the 'deep' parameters of agents such as the curvature of the utility function, the degree of competition in markets or the degree of habit formation in consumption decisions. The Altig et al. model allows us to model price and wage rigidity separately so we can distinquish the effects of labour market and product market flexibility. The model also allows us to look at the flexibility of capital markets through adjustments to the parameter governing capital adjustment costs.

The utility function in the model is increasing in consumption and decreasing in hours worked. Moreover, the consumption term is measured relative to the last period - that is, the utility function displays consumption smoothing. It is therefore the impact of shocks on consumption and hours worked that will determine the resilience of an economy by our defintion. In our model simulations, the magnitude of the responses of output, consumption and hours depend critically on the degree of rigidity in the three markets. However, when the effects of the simulated deviations around trend growth on expected lifetime utility are compared, the degree of rigidity in the three markets has very little effect. A widely used definition of resilience is based on how quickly output returns to equilibrium; if we had used that definition we would have concluded that the rigidity parameters were important determinants of resilience. By focusing on expected lifetime utility we can see that there is not a simple one-to-one relationship between the movements of the macro aggregates and welfare.

The effects on utility are especially small when the utility losses associated with shocks are compared with the utility effects of other possible policy interventions, such as increasing product market competition. This is because, at the level of the macro aggregates there is little uncertainty: the level of consumption only varies slightly. In addition to this, the class of utility functions we have investigated are almost linear in this small area around the steady state. Therefore, over the lifetime of an agent, the utility effects of positive and negative shocks just about cancel each other out.

Our conclusion could be rephrased as the costs of business cycles are small. This subject has received considerable attention in the literature. Lucas (1987) studied the costs of business cycles by calculating how much lifetime consumption an individual would be willing to give up to face a certain future consumption stream rather than a volatile stream. Using a constant relative risk aversion utility function he concluded that the costs of business cycles are small. He calculated that individuals would give up at most 0.1% of lifetime consumption to remove business cycles. In essence this is the same result that we have found.

Finally, we use the response to Lucas' results to suggest potential extensions to the Altig et al. model: any realistic analysis of the resilience of an economy requires a model to include unemployment and imperfect credit markets. Not only does lower equilibrium unemployment induce an effect on the level of output in the economy but modelling unemployment also moves away from equal, across the board effects on hours following shocks. Credit market imperfections are important because with perfect credit markets agents could insure themselves against loss of income and shocks would again have little effect on utility.

We also draw on the literature to speculate what such an extended model would look like if it were calibrated to the Dutch economy. The literature suggests that prices are less flexible in the Netherlands than the parameter estimated from US data in the Altig et al. model, whilst there is no clear consensus on the relative flexibility of wages.

1 Introduction

Resilience is a commonly heard expression in policy discussions, but what do we mean by resilience? In colloquial terms resilience suggests the ability to adjust or recover from misfortune. With regards to the macroeconomy we often think of a resilient economy as one that remains close to potential output in an international environment that is changing rapidly or is subject to shocks, such as high oil prices.

The academic literature makes little mention of the term resilience, although the response of economies to shocks has been the subject of many studies. For example, in 1986 De Long and Summers asked if increased price flexibility is stabilising when an economy is subjected to demand and supply shocks. They found that, as expected, greater nominal flexibility is always stabilising at the margin in response to supply shocks. However, unless the economy is very close to an ideal contingent-claims Walrasian economy, greater nominal flexibility is destabilising at the margin in response to demand shocks. Modern macroeconomic modelling techniques are considerably more sophisticated than those used by De Long and Summers over 20 years ago. Recently, research on shocks and output variability has been done by, among others, Cecchetti and Ehrmann (looking at the effects of monetary policy regime, 1999), Ramey and Ramey (looking at the link between volatility and growth, 1995), Ahmed et al. (who dismiss policy as causing lower output variation, 2004) Irvine et al. (looking at the role of inventories, 2002), Kose et al. (looking at the role of international financial flows, 2003) and Koskela et al (looking at the role of government size, 2003).

In light of the recent developments in macro modelling we use the model of Altig et al. (2005) to analyse the effects of variations in price flexibility, wage flexibility and capital adjustment costs on the level of utility in the face of demand and supply shocks. An economy in which the level of expected discounted utility is not lowered by a given series of shocks is our working definition of a resilient economy. We chose the Altig et al. model because it has a number of attractive features for the current study. Firstly, by modelling price and wage rigidity separately we can look at the effects of labour market and product market flexibility separately. The model also allows us to look at the flexibility of capital markets through adjustments to the parameter governing capital adjustment costs. In that sense we can compare the relative importance of product, labour and capital market flexibility for resilience.

Our model simulations suggest that deviations around trend output have a much smaller impact on utility than the changes in the level of output. Furthermore, the effects of price rigidity, wage rigidity and capital adjustment costs on the utility loss associated with deviations from trend are small.

The remainder of this paper is organised as follows. Section 2 discusses how shocks are defined and the competing definitions of resilience. The adjustment mechanisms used to respond to shocks are discussed in Section 3. The effects of policies and institutions on these adjustment mechanisms are also considered. Section 4 introduces the Altig et al. (2005) model. Section 5 contains the results of our model simulations. Section 6 interprets these results and discusses the limitations of the current paper, whilst Section 7 concludes.

2 What is meant by resilience?

In layman's terms, resilience can be thought of as the ability to adjust or absorb a shock. This brings up two key questions: What do we mean by shocks? How do we define resilience?

2.1 Shocks

Empirical work, especially that using the VAR methodology, usually defines shocks as simply those variations in a given series that cannot be explained by the empirical model being used. This is broader than the definition used by Karanassou et al. (2004) who define a shock S at period t as the change in an exogenous variable X_i from some fixed point in time T (base period) to period t: $S_{it} = X_{it} - X_{iT}$, where $t > T$. The distinction between defining shocks as affecting only exogenous variables or affecting all variables reflects the emphasis of a study. Studies employing the exogenous shocks only definition are primarily interested in analysing the effects of non-domestic shocks, which are often thought of as exogenous variables. The all variables definition is broader than and encompasses the exogenous only definition. Regardless, shocks are unexpected and unpredictable.

It is almost always of interest to distinguish between different classes of shocks. This is most usefully done as a series of dichotomies. It is natural in economics to distinguish between demand and supply shocks, such as done by Blanchard and Quah (1989). In empirical work, demand and suply shocks are often defined by their effects on the economy rather than being from some underlying supply or demand system. For example, supply shocks are defined by Blanchard and Quah as those shocks that have a permanent effect on the level of output whereas demand shocks do not. However, it is also possible to think of transitory supply shocks such as a temporary increase in a factor of production, such as labour. This discussion of definition by effect leads to another common distinction that is often made between permanent structural shocks, such as the rise of China, and temporary shocks, such as one-off tax. Empirically, in a stationary world the distinction between permanent and temporary shocks is simple: a temporary shock is where the impulse itself returns to zero, whereas a permanent shock does not. However, in a world with integrated processes single, one-period impulses can have permanent effects. In light of this it is probably easier to use a strict definition of temporary shocks: those whose effects die out over time rather than those where the impulse itself dies out. Permanent shocks are those that have lasting effects.

It may also be of interest to look at which markets the shocks originate in, such as capital markets, labour markets or goods markets. A distinction can also be made between shocks in domestic and foreign markets. For example, strong wage demands by employees may undermine the international competitiveness of an economy, as well as having a number of effects in domestic markets. A similar shock in a foreign country may well look more like a demand shock from the point of view of domestic industry. Some of the most important and lasting shocks are external or even global shocks. Examples of such global shocks are advances in technology like the ICT revolution that have the potential to affect all countries. The ICT revolution has not affected all countries in the same way: some countries are initiators and some followers. Similarly, oil price shocks affect all economies, although not necessarily symmetrically across countries. Oil price shocks will have different effects in heavily oil dependent importing countries than they will have in the OPEC countries. Another important distinction between domestic and foreign shocks is that policy makers can potentially go directly to the source of the domestic shock to mitigate its effects, whereas this is unlikely to be possible with external shocks. For example, if workers in a domestic industry strike the government can get involved in negotiations to end the strike. This is not possible if workers in a foreign industry strike.

Shocks can be positive or negative. The importance of the distinction between positive and negative shocks is related to the question whether the economy displays asymmetric responses to shocks. For example, the effects of an oil price rise may be larger than the effects of a fall. However, the asymmetric distribution of oil price movements (large rises are more frequent than large falls) has made this point difficult to establish empirically.

In the Altig et al. model there are three types of shock. These are a money shock and two technology shocks. There is quite some history in macroeconomics of using money shocks as a proxy for general aggregate demand shocks and the same is true for the use of technology shocks to represent supply shocks.

2.2 Resilience

No clear, universally accepted, definition of resilience exists in the literature. The definition used in each study appears to depend on the model being used. For example, according to Drew et al. (2004), resilience can be thought of as how quickly an economy returns to equilibrium following a shock. Whilst this appears a natural definition at first sight, it takes no account of the severity of disequilibria, which is also important. For instance, consider two economies, one where GDP goes to zero for 6 months following a shock before returning to potential and one where GDP is lowered by 5% for 7 months. Since only the duration is measured the first economy would be regarded as more resilient on this measure. This does not tally with a colloquial understanding of resilience since the total amount of consumption foregone is much higher in the former than the latter.

In contrast, Briguglio et al. (2005) define resilience by way of an analogy: that of resilience to exposure to the influenza virus. There are at least three senses in which resilience is understood. In the event that a person is exposed to the virus, she may: (a) get infected, but recover quickly; (b) withstand the effect of the virus, possibly by having been immunised; (c) avoid the virus altogether by having stayed away from infected sources. This paper will focus on the first two components of this analogy as they relate to an economy: (a) the ability of an economy to recover quickly following adverse shocks; (b) the ability to withstand shocks or the sensitivity of an economy to shocks. As far as the second part of this definition is concerned, it is often possible to use financial instruments to insure oneself against the effects of shocks. For example, in the face of temporary shocks to income, consumers can continue to enjoy a steady utility level by consuming out of accumulated saving or by borrowing in financial markets. The ability of an economy to avoid shocks, which is analogous to point c is not considered in our model. This type of resilience is considered to be inherent, and can be considered as the opposite of economic vulnerability.

Vulnerability is defined as the proneness of an economy to exogenous shocks lying outside its control (Briguglio et al., 2005). The risk of being adversely affected by an external shock is a combination of two elements: vulnerability (exposure to external shocks arising from intrinsic features of the economy such as economic openness) and resilience (coping ability enabling the country to withstand or bounce back from adverse shocks). Vulnerability is inherent in the structure of the economy, such as how diversified the industry of an economy is, and depends on different factors to resilience. They therefore require different policy or governance measures if one wishes to decrease the vulnerability or increase the resilience of an economy. In this paper we only investigate resilience.

3 Key mechanisms

We can translate the analogy of Briguglio et al. into the traditional language of macroeconomics by talking about equilibrium mechanisms instead of the ability to recover quickly and by talking about transmission mechanisms instead of the ability to withstand shocks. To fully discuss transmission mechanisms and equilibrium mechanisms for all shocks impacting an economy would require an encyclopedia of modern macroeconomics and will not be done here. However, it is fruitful to highlight a number of key mechanisms operating to bring specific markets back to equilibrium and to discuss some institutions affecting the mechanisms at work. We focus on those mechanisms often heard in the context of resilience. The discussion procedes on a market-by-market basis covering labour markets, goods markets and capital markets.

In a market economy prices send signals to agents. If too little of a good or service is brought to market, the price per unit will appear too low and agents will bid the price up to the market clearing price. Thus the economy is once more in equilibrium. In textbook economics this occurs quickly, but in reality it may take much longer.

In labour markets, when the price of labour is too high there is involuntary unemployment. There are a number of reasons why wages will not fall in response to excess supply. We mention causes of nominal wage rigidity including union bargaining and insider-outsider theory (see Lindbeck and Snower, 1989) and efficiency wages (see Shapiro and Stiglitz, 1984). The views on wage rigidity are diverse; some neoclassical economists, such as Lucas and Rapping (1969), argue that wage rigidity is an illusion and the key reason that unemployment rises in recession is that market wages fall below reservation wages. Bewley (2002) argues that the traditional explanations do not adequately explain wage rigidity. He provides a review of mainstream theories and extensive survey evidence that the main causes of wage rigidity are social. His main conclusion is that cutting wages lowers employee morale and, in turn, reduces worker effort. A similar finding is reported by Campbell and Kamlani (1997). An important possible consequence of involuntary unemployment is hysteresis. When workers have been unemployed for lengthy periods of time they lose skills and become long-term unemployed. This implies that one-off shocks can have permanent effects on the real economy through hysteresis effects.

Similarly, price (or inflation) rigidity has important consequences in goods markets. Andersen (1994) reviews theories of price rigidity noting that these can be split into two types: nominal rigidities and real rigidities. Theoretical causes of nominal rigidities include, for instance, menu costs, whereby it is costly to change prices or contracted prices where prices are literally fixed for a given period of time into the future. The policy credibility literature is also relevant here in that agents take into account expected policy developments when negotiating contracted prices. Product market competition affects real price rigidity. Prices set by any given firm in a specific market depend on the prices set by the other firms. Product market competition and industry structure are important determinants of this 'strategic complementarity in price setting'. Goods market rigidity can feed through into labour markets and vice versa.

Capital markets play an important role in allocating resources across firms and industries in an economy. Imperfections in capital markets have the potential to slow down or even prevent adjustment to shocks by inhibiting the process of withdrawing capital from unproductive uses and reallocating it to more productive uses.

Our approach models the ability of prices and wages to accurately reflect underlying market conditions by the speed with which prices and wages change on average. This is implemented by giving each firm (worker) a fixed probability of being able to reset its price (wage) each period. The lower the probability, the greater the potential misalignment between demand and supply. We model capital adjustment costs by creating a wedge between investment expenditures and the resulting increase in the capital stock. The larger the wedge, the larger the capital adjustment costs.

4 The Altig et al. model

No model can possibly hope to address all of the points raised above so we have chosen a model that enables us to look at an important selection of these. The model chosen is that of Altig et al. (2005); it represents the state of the art of New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model building. These models are current practice in the academic literature combining a microfounded structural approach with an ability to mimic the properties of empirical models, such as VAR models. The remainder of this section outlines the model.

The model of Altig et al. (2005) allows us to look at the effects of labour market, goods market and capital market inflexibilities in response to supply and demand shocks. The model also enables us to compare the effects of the rigidities with the effect of product and labour market competition. As discussed in the previous section, prices play a key role in allocating resources in a market economy.

It is a micro-founded dynamic stochastic general equilibrium model. That is, the model of the macroeconomy is built up from maximising agents, whereby households maximise utility and firms maximise profits. Therefore, the characteristics of the model can be traced back to the 'deep' parameters of agents such as the curvature of the utility function, the degree of competition in markets or the degree of habit formation in consumption decisions. These parameters are thought to be less likely to depend on the specific policy regime under which the model is estimated; hence, we can be more confident that when we undertake policy experiments in the model we are not subject to the Lucas critique.

The model comprises four blocks: households, final goods market firms, intermediate goods market firms and monetary policy. Households maximise utility, which depends positively on the level of consumption of the final consumption good and negatively on the hours of labour they supply to intermediate goods firms. Final goods firms are perfectly competitive (they are price takers) and take the output of intermediate firms and aggregate it into the final good. Intermediate goods firms are monopolistically competitive, which is modelled using the Dixit-Stiglitz approach. They set prices and output to maximise profits. To produce their output, the intermediate firms use capital, which they own themselves (that is, capital is firm-specific), and a differentiated labour input, which is supplied by households. Finally there is a monetary authority who controls the money supply.

The demand shocks come from shocks to the money supply. There is a longer history of using monetary shocks to proxy as general demand shocks in macroeconomics (see, Romer, 2000, chapter 6, for examples). The supply shocks come from two different types of technology shocks, one to labour productivity and one to the price of investment goods.

4.1 The final goods sector

Final goods, Y_t, are made by combining intermediate goods from all i industries, $y_t(i)$, using a Dixit-Stiglitz (1979) aggregator

$$Y_t = \left[\int_0^1 y_t(i)^{\frac{1}{\lambda_f}} di \right]^{\lambda_f}, \quad 1 \leq \lambda_f \leq \infty. \tag{4.1}$$

The final goods sector is perfectly competitive. The parameter λ_f measures the degree of competition in the market. This parameter also influences the degree of strategic complementarity in price setting for intermediate firms, if we follow Woodford's (2003) terminology, or the degree of real rigidity if we follow Romer (2000). The degree of strategic complementarity in price setting measures how willing firms are to have prices that are different from those set by other firms. For example, in a perfectly competitive market you must set your price equal to all other firms but as a market becomes less competitive firms can charge a different price to others and still face a finite demand. In the extreme case of highly differentiated goods, a firm doesn't have any direct competitors and is free to choose it's own price. In conjunction with profit maximisation, this also gives a price level determination equation, that is, an equation for the determination of the price of the final good, Y_t

$$P_t = \left[\int_0^1 p_t(i)^{\frac{1}{1-\lambda_f}} di \right]^{1-\lambda_f}, \quad 1 \leq \lambda_f \leq \infty, \tag{4.2}$$

where $p_t(i)$ is the price of the ith intemediate good.

4.2 The intermediate goods sector

The intermediate goods sector is monopolistically competitive. This means that there are many different firms whose products are similar but not perfect substitutes for each other. Each differentiated good, i, is produced by the following production function

$$y_t(i) = \begin{cases} K_t(i)^{\alpha} (z_t h_t(i))^{1-\alpha} - \phi z_t^* & \text{if } K_t(i)^{\alpha} (z_t h_t(i))^{1-\alpha} \geq \phi z_t^* \\ 0 & \text{Otherwise} \end{cases}, \tag{4.3}$$

where, $K_t(i)$ is the capital employed in industry i and $h_t(i)$ is the labour input in industry i, measured in hours. The parameter z_t represents neutral technology and the parameter z_t^* represents the overall level of technology. The overall technology level, z_t^*, depends on the level of neutral technology, z_t, and the level of embodied technology, Υ_t,

$$z_t^* = \Upsilon_t^{\frac{\alpha}{1-\alpha}} z_t. \tag{4.4}$$

ϕ parameterises fixed costs assuring equilibrium profits to be zero in steady state, ie. there is no entry or exit into markets in this model. Normally, in a model with exogenous growth, all real steady state variables will grow at the exogenous rate of technological progress including profits.

This raises the question of how many new firms will enter the market, and how they do so. This is an unnecessary complication which is avoided by the adjustment employed here.

But what do we mean by capital embodied technology? It basically means that there is one process for turning inputs into consumption goods, as shown in equation 2.4, and a different process for turning consumption goods into investment goods. This relationship is assumed to be linear: $I_t = \Upsilon_t C_t$. That is, a positive embodied technology shock makes it cheaper in terms of consumption goods to make one unit of investment goods.

The distinction between neutral and embodied technology is quite 'hot' in the academic literature currently, reviving the 'do technology shocks drive the business cycle?' argument (see Fisher, 2002, who argues that embodied technology shocks are an important driving force behind the business cycle). In the 1980s when Real Business Cycle models based upon rational maximising agents were first introduced, all of the variation in output across business cycles was attributed to technology shocks. Later, models were developed in which monetary shocks accounted for 70 per cent of the observed variation. However, empirical studies found no evidence of money being so important. The question naturally arose whether money or technology shocks really drive the business cycle. Recent studies, including the Altig et al. study, have managed to come closer to the empirical data by incorporating neutral technology.

The growth rates of the technology parameters are defined as follows

$$\frac{z_t^*}{z_{t-1}^*} = \mu_{z^*,t} \quad , \quad \frac{z_t}{z_{t-1}} = \mu_{z,t} \quad , \quad \frac{\Upsilon_t}{\Upsilon_{t-1}} = \mu_{\Upsilon,t}.$$

As mentioned above, the growth rates of the technology parameters follow autoregressive processes (a hat indicates percentage deviation from the steady state),

$$\mu_{z^*,t} = \mu_{\Upsilon,t}^{\frac{\alpha}{1-\alpha}} \mu_{z,t}, \tag{4.5}$$

$$\hat{\mu}_{z,t} = \rho_{\mu_z} \hat{\mu}_{z,t-1} + \varepsilon_{\mu_z,t}, \tag{4.6}$$

$$\hat{\mu}_{\Upsilon,t} = \rho_{\mu_\Upsilon} \hat{\mu}_{\Upsilon,t-1} + \varepsilon_{\mu_\Upsilon,t}. \tag{4.7}$$

4.2.1 Timing

The timing of decisions is essential in our model. The intermediate goods firms observe the level of technology, then set their prices. Subsequently the shock to monetary policy is realised, which determines the level of demand. Finally firms choose quantities of capital and labour to satisfy the level of demand at the prices they have already set.

Firms are price takers in factor markets. The objective function they maximise is

$$\begin{aligned} \mathrm{E_t} \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} \Big\{ & P_{t+j}(i) y_{t+j}(i) - P_{t+j} R_{t+j} w_{t+j}(i) h_t(i) \\ & - P_{t+j} \Upsilon_{t+j}^{-1} \left[I_{t+j}(i) + a(u_{t+j}(i)) \bar{K}(i)_{t+j} \right] \Big\}. \end{aligned} \tag{4.8}$$

In words, firms maximise the discounted sum of future profits. The first term with the brackets is the revenue in period t. The second term is the cost of the labour input, where it is assumed that the firm must borrow at gross rate R_t to pay for the cost of wages, w_t, up front. The third term is the cost associated with capital utilisation, $a(u_t(i))$, and capital accumulation (ie. investment). In the ACEL model, capital is firm-specific, which means that firms own their own capital and the rate of return to capital does not have to be equal across all firms at all times.

However, not all intermediate goods firms get to re-optimise prices every turn because of nominal rigidity. Intermediate goods firms set prices according to the Calvo (1983) mechanism. That is, there is a constant probability, $1-\xi_w$, that each firm will be able to reoptimise its nominal price. Otherwise prices are updated by the inflation rate in the last period. That is, they are set according to

$$P_t(i) = \pi_{t-1} P_{t-1}(i). \tag{4.9}$$

It is costly to adjust capital around the steady state. The capital stock employed by a given industry is composed of the capital stock last period adjusted for depreciation at rate, δ, plus the amount of new capital added by investment. Since there are adjustment costs the amount of new capital added by investment takes the form of the function $F(.)$.

$$\bar{K}_{t+1}(i) = (1-\delta)\bar{K}_t(i) + F(I_t(i), I_{t-1}(i)). \tag{4.10}$$

$$F(I_t(i), I_{t-1}(i)) = \left(1 - S\left(\frac{I_t(i)}{I_{t-1}(i)}\right)\right) I_t. \tag{4.11}$$

The function $S(.)$ parameterises the adjustment costs. Evaluated at the steady state the level, $S(.) = 0$, and the first derivative, $S'(.) = 0$; adjustment costs are imposed through the second derivative.

4.3 Households

Household j maximises the following objective function

$$\begin{aligned}\sum_{t=0}^{\infty} \beta^t \Bigg\{ & \log(C_{t+l} - bC_{t+l-1}) - \psi_L \frac{h_{j,t+l}^2}{2} \\ & + \Lambda_t \left[R_t (M_t - Q_t + (x_t - 1) M_t^a) + A_{j,t}\right. \\ & \left. + W_{j,t} h_{j,t} + Q_t + D_t - (1 + \eta(V_t)) P_t C_t - M_{t+1}\right] \Bigg\},\end{aligned} \tag{4.12}$$

where preferences over consumption and leisure are given by

$$E_t^j \sum_{l=0}^{\infty} \beta^{l-t} \left[\log(C_{t+l} - bC_{t+l-1}) - \psi_L \frac{h_{j,t+l}^2}{2}\right] \tag{4.13}$$

where log is the natural logarithm. This function is a special case of the Constant Relative Risk Aversion family of preferences over consumption. This formulation of preferences incorporates consumption smoothing through the parameter b; agents evaluate utility from consumption relative to what they consumed last period. Households dislike work, which is modelled quadratically through hours worked, h. The budget constraint of the household can be broken down into parts. The first part, $R_t\left(M_t - Q_t + (x_t - 1) M_t^a\right)$, represents the interest paid on start of period money balances, M_t, plus cash balances, Q_t, plus the monetary injection from the central bank, M_t^a, which grows at rate, x_t. The following four variables are net cash inflow from state contingent securities, $A_{j,t}$, wage income, $W_{j,t}h_{j,t}$, cash and the household's share of profits, Q_t. This must equal nominal expenditure, $(1+\eta(V_t))P_tC_t$, and money balances taken to the next period, M_{t+1}. Following Erceg et al. (2000), households supply a differentiated labour service, ie. the labour market is also monopolistically competitive

$$H_t = \left[\int_0^1 h_{j,t}^{\frac{1}{\lambda_w}} dj\right]^{\lambda_w}, \tag{4.14}$$

where H_t is the aggregated labour input into production. As in the case with intermediate goods, λ_w, measures the degree of competition in labour markets and the degree of strategic complementarity in wage setting for households. Wage rigidity is also modelled with a Calvo mechanism with parameter ξ_w.

4.4 Monetary policy

Monetary policy is modelled as a policy rule that automatically adjusts the money supply in the face of shocks. It is assumed that the monetary authority can immediately distinguish between the three shocks. The growth rate of the money supply, $\hat{x}_t$, can then be written as as combination of the monetary response to each of the three shocks

$$\hat{x}_t = \hat{x}_{zt} + \hat{x}_{Mt} + \hat{x}_{\Upsilon t} \tag{4.15}$$

where $\hat{x}_{zt}$ is the monetary response to money supply shocks, $\hat{x}_{\Upsilon t}$ is the response to embodied technology and $\hat{x}_{Mt}$ is the response to neutral technology. The individual responses are modelled as ARMA processes as follows

$$\hat{x}_{M,t} = \rho_{xM}\hat{x}_{M,t-1} + \varepsilon_{M,t}, \tag{4.16}$$

$$\hat{x}_{z,t} = \rho_{xz}\hat{x}_{z,t-1} + c_z\varepsilon_{z,t} + c_z^p\varepsilon_{z,t-1}, \tag{4.17}$$

$$\hat{x}_{\Upsilon,t} = \rho_{x\Upsilon}\hat{x}_{\Upsilon,t-1} + c_\Upsilon\varepsilon_{\Upsilon,t} + c_\Upsilon^p\varepsilon_{\Upsilon,t-1}. \tag{4.18}$$

Here, $\varepsilon_{M,t}$ is a monetary policy shock, $\varepsilon_{z,t}$ is an innovation in neutral technology and $\varepsilon_{\Upsilon,t-1}$ is an innovation in capital embodied technology.

4.5 Calibration

The model is solved for the steady state and then linearised around the steady state. The linearised model is calibrated to reproduce as closely as possible the stylised facts as given by a VAR analysis. That is, a VAR model with comparable data for the US is estimated and the responses of the VAR model to monetary, neutral technology and embodied technology shocks are calculated. The DSGE model is then calibrated to reproduce these responses as closely as possible. The calibration results in each of the three shocks being responsible for about a third of the variation in output (see Altig et al. for more details). As described in Christiano et al. (2005), the calibration is done as follows

$$J = \min_{\zeta} \left[\hat{\Psi} - \Psi(\zeta)\right]' V^{-1} \left[\hat{\Psi} - \Psi(\zeta)\right], \tag{4.19}$$

where $\hat{\Psi}$ denotes VAR responses, Ψ denotes DSGE model responses and V denotes a diagonal matrix of sample variances of the $\hat{\Psi}$.

4.6 Discussion - using a closed economy model

The model we have described here contains no foreign variables and no exchange rates: it is a closed economy model. It may seem strange for modellers interested in applications to a small open economy like the Netherlands to be using a closed economy model. This seemingly strange choice comes from difficulties encountered when modelling an open monetary economy with free capital flows. We need a monetary model in order for nominal price rigidity to have any meaning. According to Neiss and Nelson (2003) each monetary model used for policy analysis should include the following three features

1. Central bank control of nominal rates and considerable control of short-term real rates
2. Inflation persistance
3. Investment in physical capital very important for cyclical fluctuations and adjustment

Open-economy DSGE models have difficulties capturing these features. Either there is no endogenous variation in short-term real rates, no inflation persistance (McCallum and Nelson, 2000) or no endogenous physical capital. To circumvent this shortcoming, Neiss and Nelson propose adjusting the parameters of their closed-economy model to approximate an open-economy. They achieve this by making consumption more interest elastic than standard estimates of the elasticity of domestic consumption to real interest rates suggest. Note that in a standard closed-economy DSGE model, consumption depends on current and future real interest rates through the Euler equation. Net exports depends on the real exchange rate and hence on the current and future real interest rates as well. The non-investment aggregate demand, ie. consumption in a closed economy model, proxies for non-investment aggregate demand in an open-economy, as consumption is augemented with net exports.

Neiss and Nelson go in to detail that US data (see Hall, 1988; McCallum and Nelson, 1999; Fuhrer, 2000; and Ireland, 2000) indicates an interest elasticity of consumption of 0.2. Neiss and Nelson use a value of 0.6 for the UK. The Netherlands is smaller still and, as a result of being in the single currency, should be even more interest elastic. The ACEL model, by virtue of the log utility, has an interest elasticity of consumption of 1. Hence, following the Neiss and Nelson argument, the value of one yields an appropriate value for the small, open-economy of the Netherlands. Moreover, log utility is widely used in the DSGE literature.

Given the current state of the DSGE literature we are left with a choice: either use an open-economy model and ignore capital markets, or use a closed-economy model as an approximation to an open-economy. Since the importance of capital markets is an important element of the resilience debate, the latter option appeared to be the lesser of two evils.

4.7 Simulating the model

The model is simulated by generating a series of exogenous variables, s_t, to feed into the model

$$s_t = P s_{t-1} + \varepsilon_t. \tag{4.20}$$

There are eight exogenous variables in the vector s_t. They are the response of the monetary authority to monetary shocks, $\hat{x}_{M,t}$, the monetary shock, $\varepsilon_{\mu_z,t}$, the growth rate of neutral technology, $\hat{\mu}_{z,t}$, the shock to the growth rate of neutral technology, $\varepsilon_{\mu_z,t}$, the response of the monetary authority to neutral technology shocks, $\hat{x}_{z,t}$, the growth rate of embodied technology, $\hat{\mu}_{\Upsilon,t}$ the shock to the growth rate of embodied technology, $\varepsilon_{\mu_\Upsilon,t}$, and the response of the monetary authority to embodied technology shocks, $\hat{x}_{\Upsilon,t}$. The matrix P described in equation (4.20) reads

$$P = \begin{pmatrix} \rho_M & 0 & & & & & & \\ 0 & 0 & & & & & & \\ & & \rho_{\mu_z} & 0 & 0 & & & \\ & & 0 & 0 & 0 & & & \\ & & 0 & c_z^p & \rho_{xz} & & & \\ & & & & & \rho_{\mu_\Upsilon} & 0 & 0 \\ & & & & & 0 & 0 & 0 \\ & & & & & 0 & c_\Upsilon^p & \rho_{x\Upsilon} \end{pmatrix} \tag{4.21}$$

and $\varepsilon_t' = \left(\varepsilon_{M,t}, \varepsilon_{M,t}, \varepsilon_{\mu_z,t}, \varepsilon_{\mu_z,t}, c_z \varepsilon_{\mu_z,t}, \varepsilon_{\mu_\Upsilon,t}, \varepsilon_{\mu_\Upsilon,t}, c_\Upsilon \varepsilon_{\mu_\Upsilon,t}\right)$. The parameters in the P matrix come from the processes governing technological progress (equations 4.6 and 4.7) and the monetary policy rule (equations 4.16 to 4.18). As described earlier, they are calibrated so that the model responses fit the responses from a VAR.

Once we specify a series for each of the three shocks, the exogenous variables are determined. Each series of shocks is 1,000 periods long to facilitate the computation of the present value of these events. We simulate our model for these 1,000 periods.

4.8 Measuring resilience

We conduct a Monte Carlo simulation to evaluate the resilience of a model economy under given market rigidities. Each parameterisation is run 10,000 times with a new series of exogenous shocks each time. The resulting level of discounted utility is given by

$$\sum_{l=0}^{\infty} \beta^{l-t} \left[\log\left(C_{t+l} - bC_{t+l-1}\right) - \psi_L \frac{h_{j,t+l}^2}{2} \right]. \tag{4.22}$$

The mean of the 10,000 discounted utilities recorded was calculated to give us the expected discounted utility.

5 Results

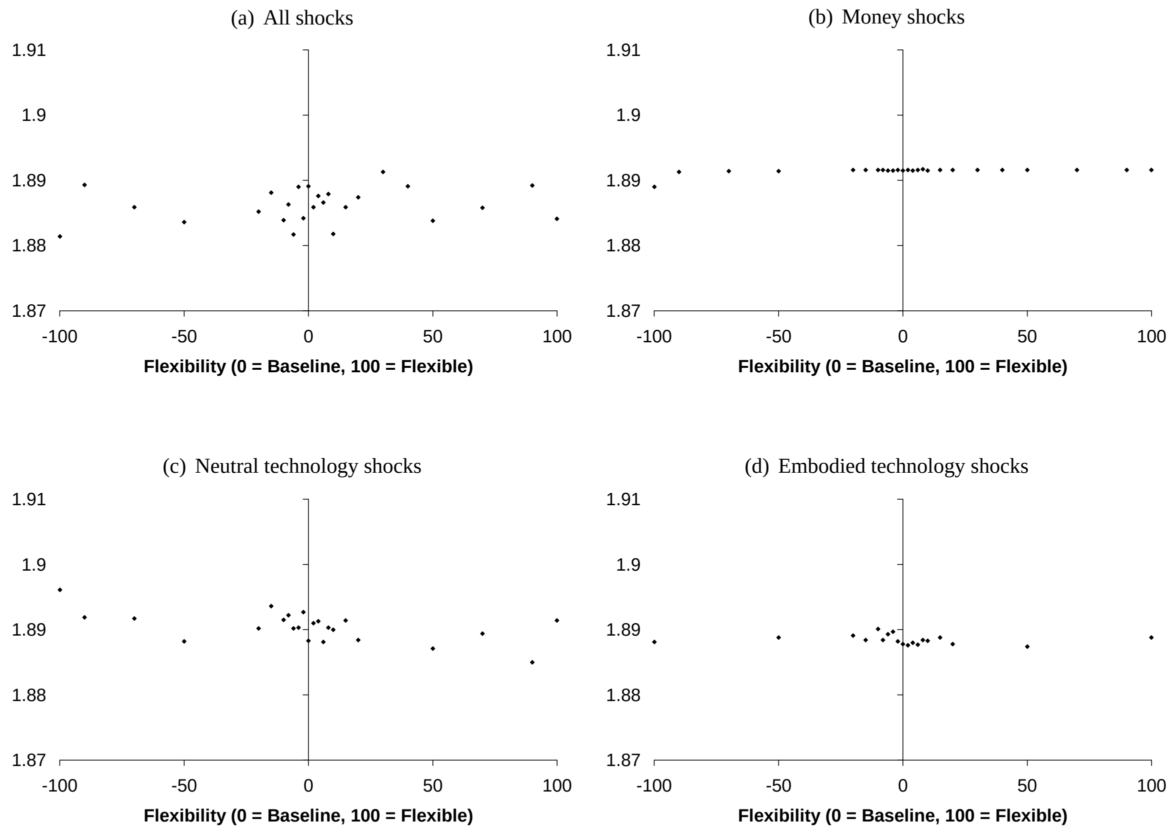
The effects of varying degrees of rigidity on expected utility can be seen in figure 5.1. The baseline set of parameters is given the value zero in the figures. The price and wage rigidity parameters vary from the baseline to fully flexible (all agents reset their wage every period), which is given the value 100 in the figures, to fully inflexible, which is given the value -100. Capital adjustment costs are also represented in a similar way in the figures. The baseline capital adjustment cost is given the value zero, no adjustment costs are given the value 100 and costs twice the baseline level are given the value -100. In the figures, all rigidity parameters are adjusted at equal intervals (ie. wage, price and capital rigidity are all set at -50). The results demonstrate that there is no discernable relationship between the rigidity parameters and the level of expected utility when all three shocks are simulated together. The figure is not smooth, however, indicating that the accuracy of 10,000 Monte Carlo simulations of the three shocks is only sufficient to distinguish between changes of expected utility in the region of 0.5% of the baseline level - the y-axes go from approximately 99% of the baseline level of utility to 101%. The remaining three figures shows that this lack of accuracy is caused mainly by the neutral technology shocks, since that is the only one displaying a similar variation across the parameterisations. The figure for the money shocks is virtually a smooth straight line. The exception is the very inflexible case where prices and wages have less than a 1% chance of adjusting each period, this results in slightly lower expected utility. As with the simulations for all shocks, the simulations with neutral technology shocks display no discernable relationship between flexibility and expected utility. The same is true for embodied shocks.

As a consequence of finding no relationship when combining the rigidities it is of little interest to look at the rigidity parameters individually. They demonstrate the same lack of relationship and are not shown.

An important point to note, however, is that if we were to choose a different definition of resilience we would get a different conclusion. Figure 5.2 shows the responses of output, consumption, hours worked and capacity utilisation to a monetary policy shock. As the flexibility parameters are changed from very inflexible (less 100 in the figure), through the baseline specification to very flexible (more 100), the responses of the macroeconomic aggregates become significantly smaller and less persistent. Had we taken the definition employed by Drew et al. we would have concluded that market rigidities were very important for resilience. This is in stark contrast to our conclusion.

So why is there no relationship between expected utility and the rigidity parameters, even though we observe marked differences in the responses of the aggregates? Since monetary shocks are random and temporary, positive and negative shocks will average each other out in the long run in terms of deviations from the steady state quantity of money. The utility effects depend on two things: 1) how consumption and hours vary in response to money shocks and 2)

Figure 5.1 Effect of market rigidities on expected utility

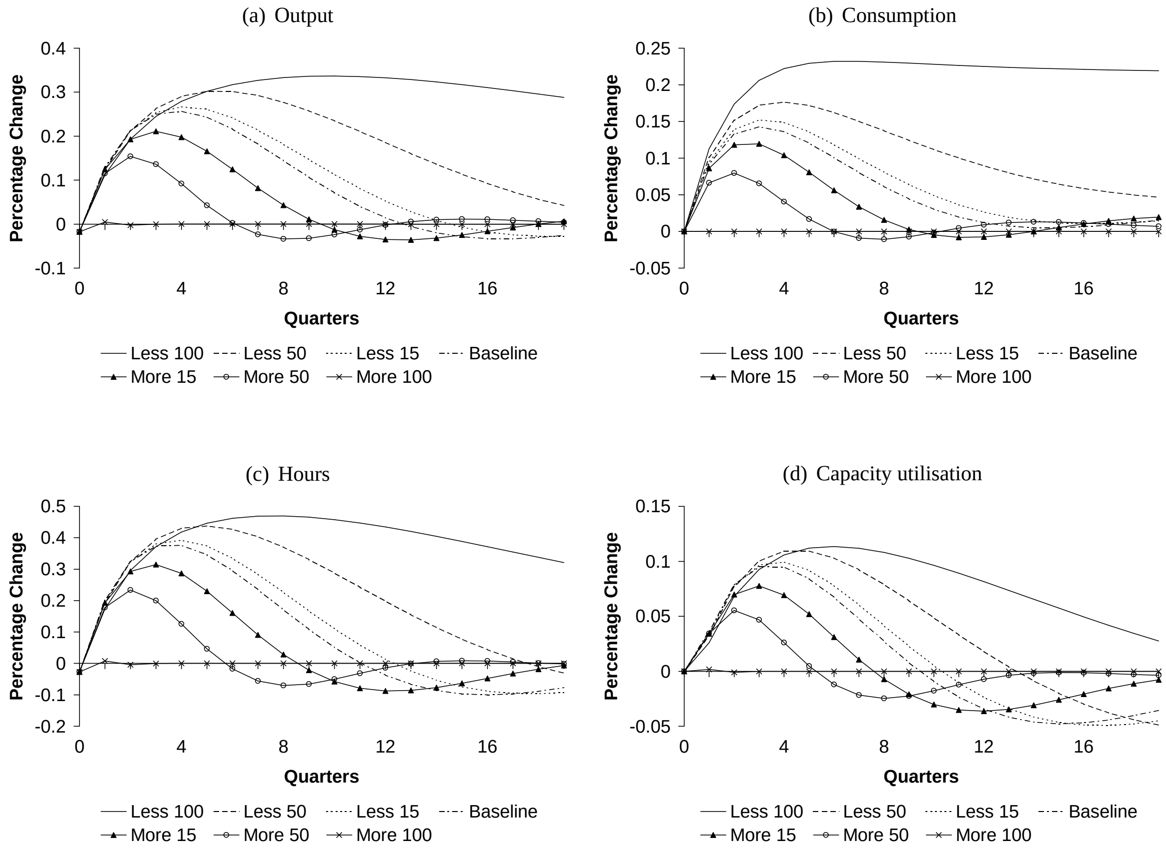


how utility varies with changing hours and consumption. The log linearised model is symmetric around the steady state. Therefore the responses of consumption and hours to money shocks are also symmetrical; they too cancel each other out on average. However, the variation of utility with the variation in consumption and hours is not symmetric. The effect of consumption on utility is logarithmic and the effect of hours is quadratic. The reason why we observe such a small effect is that these are almost linear in the region of the steady state for the magnitude of shocks we investigate. That is why the utility effects of the rigidity parameters is so small.

Two ways of getting around this spring readily to mind: either make the distribution of the monetary shocks asymmetric or move away from log utility. Neither of these is particularly attractive. The model is calibrated to and based on normally distributed shocks from the VAR model. Whilst there is evidence that monetary policy shocks are not normally distributed, [1] there is little evidence that they are asymmetric. Moving away from log utility is not attractive either since log utility is required for the model to be consistent with balanced growth (King, Plosser and Rebelo, 1988). If one wants to look at adjustment to technology shocks in a model that reproduces real world data with growth one needs to start from a model with a balanced growth

[1] The literature suggests that monetary policy shocks are leptokurtic, ie. they are symmetric but with fatter tails than a normal distribution (see Siegfried, 2002).

Figure 5.2 Effect of market rigidities on the responses of key variables to a monetary policy shock. Rigidities vary around the baseline parameters from very unflexible (less 100) to very flexible (more 100)



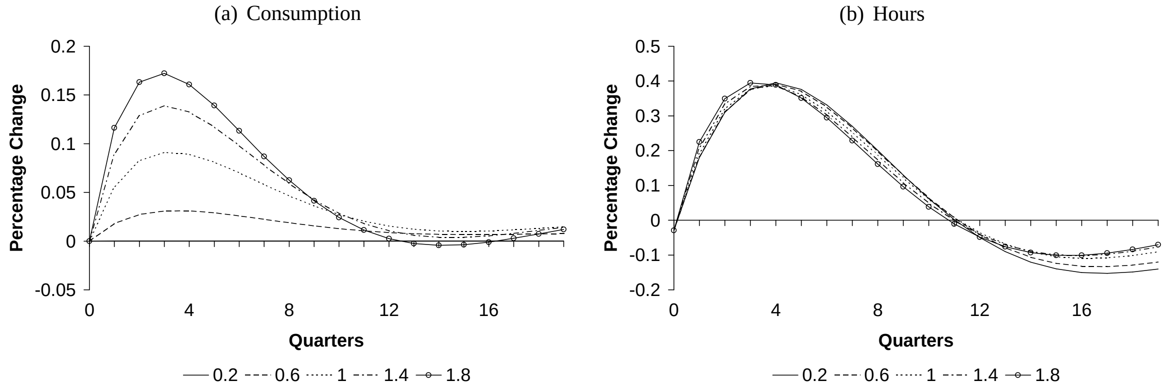
path; hence log utility cannot be avoided. Our original focus was on technology shocks; technology shocks are difficult to interpret outside of a balanced growth model. However, if we wish to focus solely on the responses to monetary shocks we can get away from log utility and penalise deviations from steady state consumption more heavily.

In light of this, we adjusted household preferences in an attempt to penalise deviations from steady state more than under log utility. To that end we have replaced log utility with constant relative risk aversion (CRRA) utility, with consumption smoothing. The new preference relation is given by

$$E_t^j \sum_{l=0}^{\infty} \beta^{l-t} \left[\frac{\left(C_{t+l} - bC_{t+l-1}\right)^{1-\frac{1}{\sigma_p}} - 1}{1 - \frac{1}{\sigma_p}} - \psi_L \frac{h_{j,t+l}^2}{2} \right]. \quad (5.1)$$

In the case where $\sigma_p = 1$ this utility function is equivalent to log utility. However, this has little effect on the results. As agents become less tolerant of deviations of consumption from the steady state level, they choose not to alter consumption in response to monetary shocks, since these are known to be stationary, zero mean shocks. This can clearly be seen in figure 5.3. Hence, the effect of these shocks on expected utility is limited.

Figure 5.3 The effect of changing the curvature of the utility function on the responses to a money shock. The baseline parameterisation is with intertemporal elasticity of substitution, $\sigma_p = 1$



In order to gauge the effects of changing the curvature of the utility function on utility we need to specify an initial level of consumption. The change in utility from equal percentage changes in consumption depends on the initial level on consumption, except in the log utility case. Starting from a technology level equal to one we calculate the utility in each period associated with remaining at the steady state. Then, in each period after the shock, we calculate the average utility from a positive and a negative shock, where both shocks are one standard deviation. Comparing this average to the level of utility in each period when there are no shocks, we take the maximum difference and calculate the discounted sum to infinity (using the discount rate set in the Altig et al. model) of being this far away from the steady state forever. The results are shown in tables 5.1 and 5.2. The total possible gain over the baseline scenario is the baseline loss, which equals 0.000777. Altering the curvature of the utility function does not greatly alter the possible gain since the maximum loss that occurs when $\sigma_p = 0.2$ is only about 1.5 times greater than the baseline loss. Hence changing the utility function does not mean that shocks are much more costly in utility terms and, consequently, the effect of the rigidity parameters on expected utility will also remain small. What we can say from tables 5.1 and 5.2 is that the utility loss is lower in the fully flexible economy than in both the baseline and fully inflexible economies. In fact, the utility loss in the flexible economy is less than 1% of the utility loss in the baseline scenario.

To further illustrate the small magnitude of the effect of rigidities on expected utility, it is of interest to compare the potential magnitude of utility gain from removing variation around the steady-state with the effects of increasing competition. Increasing product market competition by reducing the competition parameter, λ_f, from 1.01 to 1.009 increases the level of utility by 0.0015 in each period when preferences are logarithmic in utility (ie. $\sigma_p = 1$). This is 100 times larger than the total utility loss per period of 0.0000115 due to monetary shocks. Hence, making the economy more flexible is less important than competition policy.

Table 5.1 The effect of changing the intertemporal elasticity of substitution on per period utility loss

σ_p	Baseline economy	Flexible economy	Inflexible economy
0.2	1.85E-05	1.01E-07	3.79E-05
0.4	1.68E-05	9.17E-08	3.66E-05
0.6	1.43E-05	7.86E-08	2.84E-05
0.8	1.26E-05	6.98E-08	2.4E-05
1.0	1.15E-05	6.34E-08	2.11E-05
1.2	1.08E-05	5.86E-08	1.9E-05
1.4	1.04E-05	5.49E-08	1.75E-05
1.6	1.01E-05	5.2E-08	1.63E-05
1.8	9.89E-06	4.96E-08	1.54E-05
2.0	9.69E-06	4.76E-08	1.46E-05

Table 5.2 The effect of changing the intertemporal elasticity of substitution on expected utility loss

σ_p	Baseline economy	Flexible economy	Inflexible economy
0.2	0.001249	6.81E-06	0.00256
0.4	0.001133	6.19E-06	0.002476
0.6	0.000963	5.31E-06	0.001919
0.8	0.000852	4.71E-06	0.001619
1.0	0.000777	4.28E-06	0.001425
1.2	0.000727	3.96E-06	0.001286
1.4	0.000703	3.71E-06	0.001183
1.6	0.000684	3.51E-06	0.001103
1.8	0.000668	3.35E-06	0.001039
2.0	0.000655	3.22E-06	0.000986

6 Resilience and the costs of business cycles

As we saw in the previous section, the effect of shocks on utility is limited in our model. Since these shocks are the only sources of business cycle fluctuations in our model, our conclusion could be rephrased as the costs of business cycles are small. This subject has received considerable attention in the literature. Lucas (1987) studied the costs of business cycles by calculating how much lifetime consumption an individual would be willing to give up to face a certain future consumption stream rather than a volatile stream. Using a constant relative risk aversion utility function he concluded that the costs of business cycles are small. He calculated that individuals would give up at most 0.1% of lifetime consumption to remove business cycles. The cause of this result is that there is very little uncertainty regarding the time path of aggregate consumption: in recessions consumption is 1-2% below trend and in booms 1-2% above trend. In essence this is the same result that we have found.

Lucas' results are controversial in that they imply that business cycles are relatively unimportant, a view not accepted easily in the literature. Barlevy (2005) reviews the response to Lucas' paper. Barlevy argues that the responses can be grouped into four themes: 1) changing the utility function, 2) using household data rather than aggregate data, 3) models where stabilisation causes a level shift in output and 4) models where stabilisation affects the steady-state growth rate. Following Barlevy, we subsequently discuss these strands.

Barlevy concludes that most studies with different utility functions still result in low costs of business cycles. The exception is Tallarini (2000). Tallarini uses a preference structure that separates intertemporal elasticity of substitution and risk aversion (with constant relative risk aversion preferences the coefficient of risk aversion is the inverse of the intertemporal elasticity of substitution). This specification of utility is consistent with equity market data since they can generate a high equity risk premium. Once this is done, the costs of business cycles are much greater. However, the result depends on very high levels of risk aversion.

Another strand of literature argues that the aggregate level of risk is the wrong measure since this averages out the much greater variance of income for individual households due to unemployment, especially for different income groups (see, for example, Mukoyama and Sahin, 2006). This strand relies on capital market imperfections to translate the greater variance of individual income into greater variance for consumption. If individuals can borrow freely when they are unemployed individual consumption is as smooth as aggregate consumption. Since poor households with low savings rates are more likely to be credit constrained than richer households, business cycle costs are higher for them than those with higher savings. Barlevy concludes that the costs of business cycles for poor households could be between 4 and 7% of lifetime consumption, whilst the overall figure based on individual modelling is around 2.5%. For some households the costs of business cycles may even be negative due to the effect of business cycles on interest rates.

The third strand argues that stabilisation has an effect on the level of output and consumption. One explanation is that unemployment may respond asymmetrically across the cycle, so stabilising output reduces the unemployment level (see, for example, Yellen and Akerlof, 2004). Barlevy concludes that the costs of lower output might be as large as 2 percent of lifetime consumption but there is a large degree of uncertainty.

It is also possible that, by reducing uncertainty, investment increases and the rate of growth of the economy is increased. This is not a clear cut argument, however, since reducing uncertainty will lower precautionary saving and raise interest rates. Furthermore, Schleifer (1986) argues that firms invest in order to capture the excess profits in booms. If the cycle were smoothed out there would be less incentive to invest and slower growth. Barlevy concludes that stability can potentially raise growth rates and have a large effect on welfare, but that the exact effects of stabilisation are highly uncertain in this regard.

These approaches also have the potential to generate more importance for resilience in our model and point the way to interesting future work. The results suggest that further changing the utility function in our model is unlikely to alter the results. Having unemployment in our model would open up many different ways of looking at resilience, allowing us a sensible way to look at asymmetric effects across the cycle. Introducing heterogeneous agents in our model could potentially allow policy to have an effect on the level of utility. It would also allow us to potentially gauge trade offs between different groups in society, since some may value resilience more highly than others. Furthermore, those channels that work through interest rates will work differently for the Netherlands. As a small open economy these effects will work through the external balance rather than interest rates, which may induce different effects.

7 Unemployment and the other limitations of our DSGE model

7.1 The main limitations

A small theoretical model will be unable to both remain small and investigate all facets of resilience; the Altig et al. model is no exception. We list the major limitations to our current study below.

- The first limitation is that labour markets clear. The model does not allow for unemployment. We could interpret a fall in aggregate hours as akin to higher unemployment. This, however, does not improve the discussion: a fall in aggregate hours increases utility in our model, which is at odds with the conventional view that unemployment is bad. This limitation is possibly the most restrictive of the limitations listed here as it significantly reduces the suitability of our DSGE model to investigate resilience. DSGE models with unemployment exist, for example Bodart et al. (2006) and Christoffel et al. (2007). However, not all models would be suitable for studying resilience. For example, the latter model does not contain technology shocks, the response to which is important in the resilience literature. Furthermore, any model would need to incorporate credit frictions and at least some of the other points discussed in section 6, otherwise it would only be possible to draw the same conclusion as in the present study.
- A related issue is that of multiple equilibria: the log-linearised model presented here only has a single steady state. This means that the model economy will return to the same equilibrium following a given shock. In reality, this need not be the case. One of the most commonly cited reasons for multiple equilibria is hysteresis, whereby unemployed workers lose skills and subsequently have less chance of finding a new job. This leads to a permanently higher unemployment level and lower output. Matching models of unemployment, whereby workers and firms have to search to find a good match between worker and firm, often have this feature (See Den Haan, 2002 and Den Haan et al., 2001, for examples of matching models with multiple unemployment equilibria). In a world with multiple equilibria, a resilient economy is one that minimises the chance of ending up in bad equilbria. As mentioned earlier, we can't address this issue in the present model since the log-linearised model does not have multiple equilibria. [2]
- A third limitation is that the model presented here behaves symmetrically around the steady state. The log-linearisation employed to simulate model forces this to be the case. Hence there is virtually no difference between the effects of positive and negative shocks. This limitation is also linked to the previous limitation because one can think of multple equilibria as a type of asymmetry. That is, a negative shock from a good equilibrium may leave the economy in the bad

[2] The discussion above does not apply solely to labour, it also applies to the other factor of production, capital. If economic downturns cause firms to go bankrupt and it takes time for the assets of a bankrupt firm to be released and reused, then the capital of the firm is also unemployed for a period of time. Den Haan et al. (2003) develop a matching model for business that can result in multiple equilibira due to costs of bankruptcies.

equilibrium.

- The number of shocks modelled is the fourth limitation. The sources of shocks are limited to just a money shock and the two technology shocks. The model does not answer questions relating to subjects such as increased competition from Chinese goods or Indian services. It also doesn't incorporate a role for oil price shocks. Furthermore, the current paper does not address other significant issues such as the response of an economy to a large unexpected influx of labour, for example.
- The model exhibits limited inter-sectoral adjustments. Perhaps, one of the key elements of resilience is the ability of an economy to close old industries and move workers into new industries. This is not included in our model.
- The current model does not attempt to analyse the effects of policy on the variance of utility. There exists a large literature on optimal stabilisation policy and it is not our intention to repeat these exercises here. The model presented here only discusses how an economy adjusts to shocks. In that sense it ignores the crucial question of how can policy be implemented to minimise the incidence of shocks.

7.2 Market rigidities in the Netherlands: empirical evidence

Our interest ultimately lies in analysing the resilience of the Dutch economy. In order to do this we would need to extend the current model along the lines suggested in sections 6 and 7. We would also need to calibrate the model to the Netherlands. On this latter point there is already some research that we can compare to the parameters used in the current study. This comparison is fruitful in that we have seen that the flexibility of an economy determines the magnitude of the responses of the main macroeconomic variables to shocks (see figure 5.2). A model adapted along the lines discussed in sections 6 and 7 may display larger utility effects.

There is some disagreement in the empirical literature over how flexible nominal wages in the Netherlands are. Van der Welle and Den Butter (2005) conclude on the basis of studies of OECD (1999, 2000) and the European Commission (2003) that the Netherlands has the smallest nominal wage flexibility of all European countries. Other studies (Layard et al, 1998, Teulings and Hartog, 1998), however, find that the Netherlands belong to the group of most flexible countries in terms of nominal wages. These results seem to suggest that conclusions regarding the relative nominal wage flexibility of the Netherlands are not robust to various model specifications.

Hoeberichts and Stokman (2006) report survey results on the frequency of price changes in the Netherlands. Their value of once every 12 months on average is less flexible than the baseline value from the Altig et al. model. They report a value of once every 4-5 months, which concerns the US. This baseline value falls within the range of price flexibility reported for the US by Bils and Klenow (2004), Golosov and Lucas (2003) and Klenow and Kryvtsov (2005).

These three studies report estimates in the range of once every 3-6 months. Moreover, the Hoeberichts and Stokman study reports that firms review their prices much more often than they actually change them. Whether the frequency of changes or the frequency of reviews is more appropriate for comparison to the reoptimisation frequency in the model is unclear. Hoeberichts and Stokman also report that firms in more competitive markets change their prices more frequently than those in less competitive markets. In New Keynesian DSGE models competition and the effects of nominal rigidity are linked.

Montfort, Den Butter and Weitenberg (2003) conclude that in particular productivity/ technology shocks are slowly and not completely absorbed. More specifically, Balmaseda, Dolado and Lopez-Salido (2000) calculate the effects of a productivity shock on unemployment and real wages (with SVAR-model) for different countries. Their calculations suggest that the Netherlands has relatively more difficulty absorbing productivity shocks (compared to the capacity to absorb wage shocks).

Difficulties in estimating capital adjustment costs (see, for example, Hall, 2004, who argues that capital adjustment costs are small in the US, or see Hamermesh and Pfann, 1996, who list many studies that find sizeable capital adjustment costs in the US) make it hard to make a meaningful comparison between the Netherlands and the US. However, we can speculate that capital adjustment costs are higher in the Netherlands than in the US due to smaller capital markets in the Netherlands (see data in Cecchetti, 1999, for example), which make financing adjustments more difficult. Moreover, there is also evidence that capital adjustments go hand-in-hand with labour adjustments, since firms that want to use more capital will also want more labour to use the capital (see Letterie et al., 2004, which implies that the restrictions on hiring and firing labour in the Netherlands will likely raise capital adjustment costs too). Whether the difference in capital adjustment costs is enough to make a difference in the analysis is unclear.

8 Conclusion

We have used the model of Altig et al. (2005) to analyse the resilience of a model economy to shocks and this depends on specific market rigidities. We chose the level of expected utility as our measure of resilience, noting that this is therefore consistent with agent preferences in the model. Simulations suggested the effects of capital adjustment costs, nominal price and nominal wage rigidities on the level of expected utility are small, especially when compared to the effects of market competition or economic growth on the level of utility. This is because the latter shift the steady state position of the economy whilst the former only affects the position of the economy around the steady state following a given shock.

In light of this, we suggest that any realistic analysis of the resilience of an economy requires a model to include unemployment and imperfect credit markets. Not only does lower equilibrium unemployment induce an effect on the level of output in the economy but modelling unemployment also moves away from equal, across the board effects on hours following shocks. In the present model an economic downturn gives all agents a few hours extra leisure time, which they like. In reality, the effect of downturns on hours is unequally distributed: most people work a similar number of hours, some work no hours and have very low income. Another necessary step towards a realistic analysis of the resilience of the Dutch economy is calibrating the model to Dutch data.

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