Technical report on model development – Representing finance constraints in a post-Keynesian macro-sectoral model

Technical Study on the Macroeconomics of Energy and Climate Policies

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Part I. Introduction

This document describes the thinking and implementation of an explicit treatment of finance constraints for decarbonisation (and other) investments in a post-Keynesian macro-sectoral[1] model, exemplified here by the Cambridge Econometrics' E3ME energy-economy-environment model.

In many cases, the changes required to decarbonise the economy involve a substitution of capital for fossil fuel energy use. Examples include the use of renewable technologies in centralised or decentralised power generation, or the use of electricity in domestic heating or road transport, all of which entail an up-front capital expenditure in return for the elimination of current fossil fuel energy inputs. Except for small-scale projects, typically the agent may not be able to, or choose to, finance the capital expenditure out of their existing income or stock of savings: the question therefore arises as to whether financial capital will be made available by lenders and on what terms and, if this is likely to become an important obstacle to investment, whether policy action can facilitate a larger flow of financial capital to support the transition. It therefore becomes particularly important to represent the factors determining the availability of finance explicitly in economic modelling. Post-Keynesian theory is characterised by the assumption that money is created endogenously by commercial banks rather than controlled by central banks or constrained by the availability of saving (the surplus of income over consumption) by the various agents in the economy. This report describes the approach taken to implement an explicit treatment of finance in an empirical post-Keynesian macro sectoral model.

The structure of the document is as follows. Part II discusses the theoretical design and Part III the issues involved in making this design operational. Part IV reviews empirical evidence for the cost of borrowing faced by commercial borrowers and presents the econometric equations estimated to determine that commercial rate in E3ME. Part V discusses the effect of including this commercial rate of interest and a debt burden term in E3ME's investment equations and conducts some stylised simulations to show the difference that the new specification makes.

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[1] 'Macro-sectoral' here means a whole-economy model with macroeconomic aggregates and sectoral (industry/product) detail. Such models are less common than pure macroeconomic models, but sectoral detail is essential for analysis of the kind of structural economic change associated a shift from dependence on fossil fuels.

Part II. Developing the theoretical design

This section develops the logic of what we seek to capture in the empirical model. It begins with a description of the logic of a post-Keynesian model that does not explicitly recognise finance constraints, and then extends this to incorporate explicitly the constraints that earlier work in the project has identified.

Determination of investment in a post-Keynesian model without explicit representation of finance constraints

Figure 1 shows the logic for the determination of the investment in the version of E3ME that did not have an explicit treatment of finance constraints.

Figure 1: Determination of investment in a post-Keynesian model without explicit
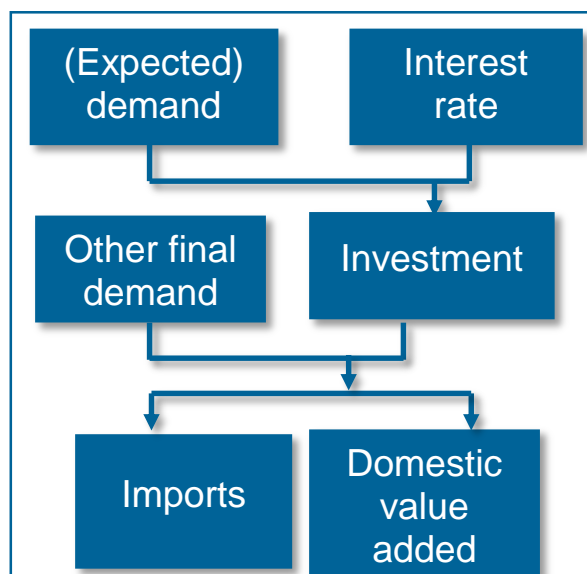
representation of finance constraints

The need for investment (GDFCF) is triggered by demand, either using econometrically-estimated equations that embody the accelerator principle or, for sectors in which a bottom-up technology approach to capacity is used (notably power generation), by an explicit model (FTT) determining how much capacity is built (and of which kind).

The impact of that higher investment is to stimulate output, incomes, other spending and imports in the usual Keynesian manner. Apart from these demand-side effects, in E3ME investment also plays a key role in contributing to long-term growth: it increases labour productivity, trade competitiveness and capacity (and hence feeds into lower product prices). In each period, the national accounts principles embodied in the model (every expenditure has a corresponding receipt for someone) ensure that total investment (plus inventory accumulation) in the economy is matched by the saving of the institutional sectors, including the Rest of the World (i.e. the balance of payments current account with an opposite sign). In practice, what this means in the case of a stimulus to investment is that, unless the economy is at full capacity, it leads to higher output, incomes and domestic saving, but the increase in domestic saving is less than the increase in investment and the balance is made up by an increase in the balance of payments deficit (inflow of capital from RoW).

The decision to undertake the investment combines (does not distinguish) the decision of the *operator* to seek to expand capacity and the decision of *those*

financing the investment that the risk-return ratio is satisfactory. The investment equation includes the interest rate but this has often not shown up as econometrically or economically significant, because year-on-year variation in investment is dominated by short-term cyclical effects and because the observable interest rate is the central bank short-term rate rather than the rate charged by commercial banks.

Apart from whatever is included in the investment equation, there is no 'financing constraint': under the usual post-Keynesian assumption of endogenous money, banks are assumed to create the credit to finance the transaction and the amount of saving undertaken in a given year by domestic institutions does not constrain investment in that year (because it does not constrain bank lending).

There could, in principle, be a short-term, real-economy capacity constraint on production of investment goods if the economy is operating at full capacity, in which case the attempt to spend more on investment will result in the model in higher inflation, including in the prices of investment goods (so that the real-terms equivalent of any given current-price level of investment is reduced), a reduction in other final demand (for example, because consumption prices are higher) and an increase in imports.

Developing the logic of an explicit representation of finance constraints

Finance constraints are relevant for all kinds of investment decision. Because the changes required to decarbonise the economy commonly involve a substitution of capital for fossil fuel energy use, finance constraints upon investment that slow the pace of that substitution are of particular interest in the context of decarbonisation policy. Different kinds of agents (for example, large companies on the one hand and households or small businesses on the other) face different kinds of finance constraints and have particular roles to play in any plausible pathway to a decarbonised economy.

In post-Keynesian theory, an economy's *capacity* to take on risk for investment (or the *willingness* of its agents to do so, or the willingness of the rest of the world to invest in the country) depends on the net wealth and gearing of its agents, not on the saving that happens to be carried out in the current year. For example, an agent that has built up substantial net financial wealth from past saving, and which is carrying little debt, can commit funds to a new investment project without much threat to its solvency. But an agent with low net financial wealth faces a larger risk of insolvency if it commits a large part of that wealth or takes on debt to invest in a new project. Similarly, an agent with moderate net financial wealth but with substantial debt (more than balanced by substantial assets), and therefore a high debt service to income ratio, can only invest in a new project by using some of its financial wealth or by increasing its debt, exposing it to a greater risk of insolvency. In boom times, when asset prices are rising and new investments are expected to be successful, the agent may regard the risk of failure as low and so be willing to commit to a new project; similarly, financial investors will be more willing to commit funds in that kind of environment.

If the regulatory environment changes to allow insurance companies and pension funds to invest more in infrastructure assets, this makes available to the infrastructure operators a *capacity* to invest in this asset type (the strong balance sheet of the insurance companies and pension funds (ICPFs)) that was not previously available. That is then reflected in a lower cost of capital for the infrastructure operator (and a greater willingness of the financial community to make finance available).

In post-Keynesian theory, the potential supply of *finance capital* in a given year is *not* the same as (or determined by) the level of 'saving' (the difference between

income and consumption for each institutional sector in any year). For institutions other than banks, the potential supply of finance capital depends on their stock of financial assets, their saving in the present year, and their willingness and capacity to borrow from banks to commit to a project. Endogenous money means that the level of saving in a given year is not closely related to the potential supply of finance capital: during a boom, saving may be low while at the same time banks are expanding their balance sheet, whereas during a recession the opposite may be true. The net result of these decisions and the outcomes for income and spending in the economy will determine the balance of saving and investment in the economy in any given year and the net inflow or outflow of capital from abroad.

When an investment project is undertaken, the operator needs to raise finance to cover the cost of the investment. When the investment expenditure occurs, the balance sheet of the project's operator shows an increase in real assets (the investment in fixed capital), an increase in financial liabilities (the new debt or in equity provided by other agents) and a reduction in financial assets (the own funds contributed by the operator).

Corresponding to that supply of financial instruments are entries on the asset and liabilities accounts for the financing institutions. For banks the additional asset is the new loan to the operator and the additional liability is a corresponding increase in bank deposits. For a financial institution (say, a pension fund) subscribing to a bond or equity issue, the additional asset is the bond or equity holding and the liability is a reduction in holdings of other financial assets (for example, bank deposits). Most households do not invest directly in projects (other than the investments by owner-occupiers in their own homes), but rather put their saving into pension funds, insurance companies and investment funds.

Figure 2 shows the logic of a theoretical post-Keynesian model that has been extended to make explicit the role of financial constraints. The effect of the extension is to incorporate:

- the macroeconomic conditions that affect the risk environment for investment, notably distinguishing the role of the (short-term) policy interest rate set by the central bank from the (long-term) rate at which lenders make finance available to borrowers; regulatory changes also play a role, typically affecting the *distribution* of finance across alternative asset classes
- the project-specific factors that raise the cost / reduce the availability of finance for riskier projects: these would not be distinguished in a purely macroeconomic model, but can be made explicit in a macro-sectoral model that distinguishes different (for example, more or less carbon-intensive) sectors and technologies
- the scale of indebtedness of the borrower, which increases the risk of failure and default

Hence, Figure 2 shows that the cost of capital to the project operator (e.g. a power generation utility company) depends on:

- the expected return on the project (because a high expected return provides a cushion to absorb unexpected negative factors)
- the risk (and other) characteristics of the project
- the credit risk of the project operator
- the macroeconomic cost of finance capital

With regard to the perceived risk (and other) characteristics of the project, these incorporate:

- country risk: all the factors that make the risk of default or disappointing returns higher in some countries than others for any kind of project
- project/technology risk: factors specific to the type of project (e.g. the risk of construction cost overruns; the risk that the technology performs less well than expected; performance risk, design risk, operation and maintenance risk; the time period required for the capital cost to be recovered; the likely price at which the operator's product can be sold in future)
- policy risk: the risk that a change in policy will lower the project's returns in future (so, the extent to which the project's success depends on policy, and the credibility of commitments to maintain or strengthen the policy regime)
- borrower risk: the borrower's credit-worthiness (track record, existing gearing)
- scale of project: this affects the administrative overhead for the financial institution; for some kinds of finance, projects have to be larger than a certain minimum size (or, perhaps, aggregated into bundles that exceed the minimum size)
- the value of collateral (which depends on whether there is a liquid market for the asset on which the loan has been secured)

With regard to the macroeconomic supply-side drivers of the cost of capital, these include:

- the costs to banks of raising finance to lend directly to project operators or indirectly (by providing loans to investment banks seeking to gear up to invest in projects): the central bank lending rate, the prudential regulatory regime with regard to bank capital (equity), structural changes that give banks access to cheaper sources of finance (e.g. securitisation), and the general level of confidence which determines the cost of equity and bond finance and banks' willingness to expand their balance sheets
- prudential regulation of other financial institutions: in particular, the rules governing the extent to which insurance companies and pension funds can invest in this kind of project

Figure 2: The logic of an explicit representation of finance constraints in a post-Keynesian model
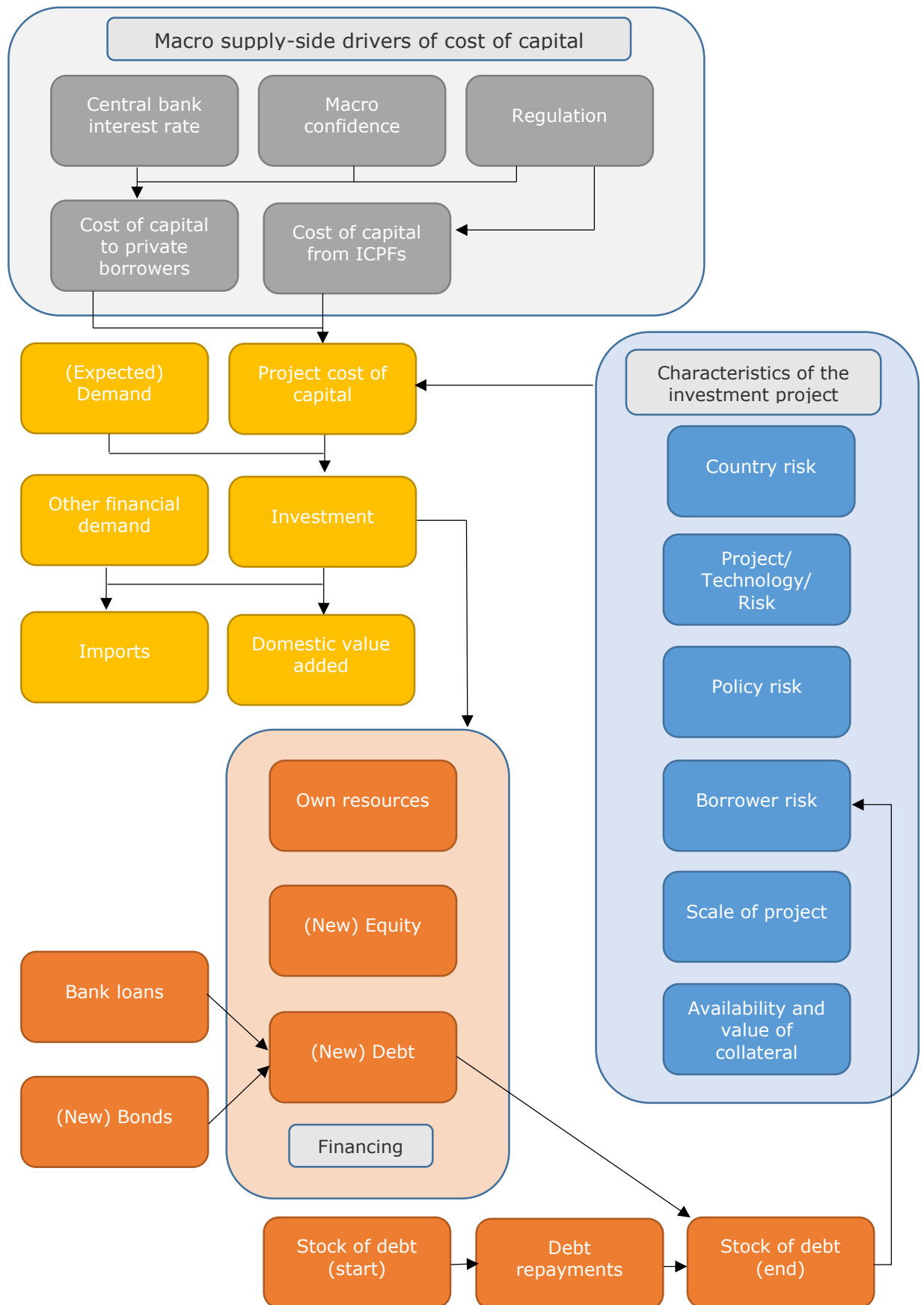
Part III. Making the design operational in an empirical model

There are a number of issues to be overcome in making this design operational.

- What we distinguish in the macro-sectoral modelling is not normally 'a project' undertaken by an operator, but annual investment by an industry. How then can we represent risk characteristics that differ by *type of project*?

  Proposed solution: In the case of power generation (the sector of most interest), the key differences in project risk characteristics are associated with particular technology types (how mature the technology is, how large a 'typical' project is). Because E3ME's FTT:Power treatment distinguishes take-up of different technologies in power generation), annual investment in a given technology will correspond to one or more projects of that technology type. We incorporate in FTT:Power assumptions for the premia associated with particular technologies so that these are reflected in the decision made over which technology to invest in.

- We cannot observe the macro cost of capital or the project cost of capital as a time series, and so we cannot estimate econometrically the impact of changes in any of the determinants on the cost of capital or the impact of the cost of capital on investment.

  Proposed solution: For the macro cost of capital we use evidence from financial market data for the interest rate on loans to commercial borrowers (or yield on commercial bonds) and model this in relation to a 'risk-free' long-term interest rate. We seek to endogenise borrower risk, making it depend on gearing (see below on the problem of getting sufficient detail on debt by industry sector). See Part IV below.

  For the project cost of capital, and the potential role of the various project characteristics noted in Figure 2, the disaggregation available in the model allows us to introduce assumptions for risk premia specific to particular countries, sectors and, for some sectors, technologies. But with the present state of knowledge, the scale of such risk premia (and the corresponding impact that policies designed to de-risk investments could have) would have to be determined on a case by case basis.

- What we observe is the outcome of an aggregation across heterogeneous agents (for example, all households or all firms in an industry), so statistics calculated for the aggregate (such as gearing) will not reflect conditions at the tails of the distribution.

  Proposed solution: We need to be aware that the level at which an institutional sector's gearing could constrain investment is lower than any value that might apply to an individual borrower. This would matter if, for example, we were attempting to represent individual projects, but we are working at the level of sectors (and, in some cases, also technologies), not particular projects and borrowers. Hence, in the kind of scenarios we are envisaging, we can still use changes in the level of a statistic calculated for the aggregate as an index of creditworthiness.

- We do not have data on assets/liabilities at anything more detailed than institutional sectors so we do not have, for example, the gearing of the power generation sector

  Proposed solution: We make assumptions for the 'typical' extent to which investment depends on debt (as opposed to retained profits or equity) and for the repayment period on loans and bonds. We then construct, from historical investment data, an estimate of the stock of loans outstanding in each year, for each investing sector. For any given type of decarbonising investment (according to the classification we established in an earlier report in this project[2] and drawing on funding examples there), we assume that a particular mix of sources of funds will be needed, to reflect 'normal' risk-sharing arrangements (funds put in by the operator, bank loan, bonds and new equity). That mix varies across countries according to the tradition of the country (especially bank loans versus bonds). See Part V below. Policies that underwrite loans could be represented by preventing the increase in gearing that would otherwise be associated with investments.

- Macro-sectoral models are sometimes used for simulations in which the take-up of energy technologies and the resulting in change in energy use are imposed as assumptions (drawing on the outputs of an energy system model), and the macro-sectoral model is used solely to derive the economic implications. How will such simulations be carried out with the extended model described here?

  In this kind of simulation, since the required investment by sector and technology is introduced by assumption from the energy system model, the considerations set out here will largely be ignored/overwritten. However, the energy system model may also have information about the financial incentives that were necessary, in that model, to bring about the decision to make the investment, and if so those incentives could be incorporated in E3ME so as to make the simulation more complete. For example, it might be assumed in the energy system model that a feed-in tariff guarantees the electricity price that the investment in a particular technology will earn, in which case that information should be incorporated in E3ME to capture the macroeconomic impact of a higher electricity price paid by consumers.

  Figure 3 summarises how these considerations have affected the operational version of the design set out in Figure 2.

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[2] Trinomics (2017) *Assessing the European clean energy finance landscape, with implications for improved macro-energy modelling*, Deliverable D3 in the project 'Study on the Macroeconomics of Energy and Climate Policies'.

Figure 3: The operationalised representation of finance constraints in E3ME compared with the theoretical design
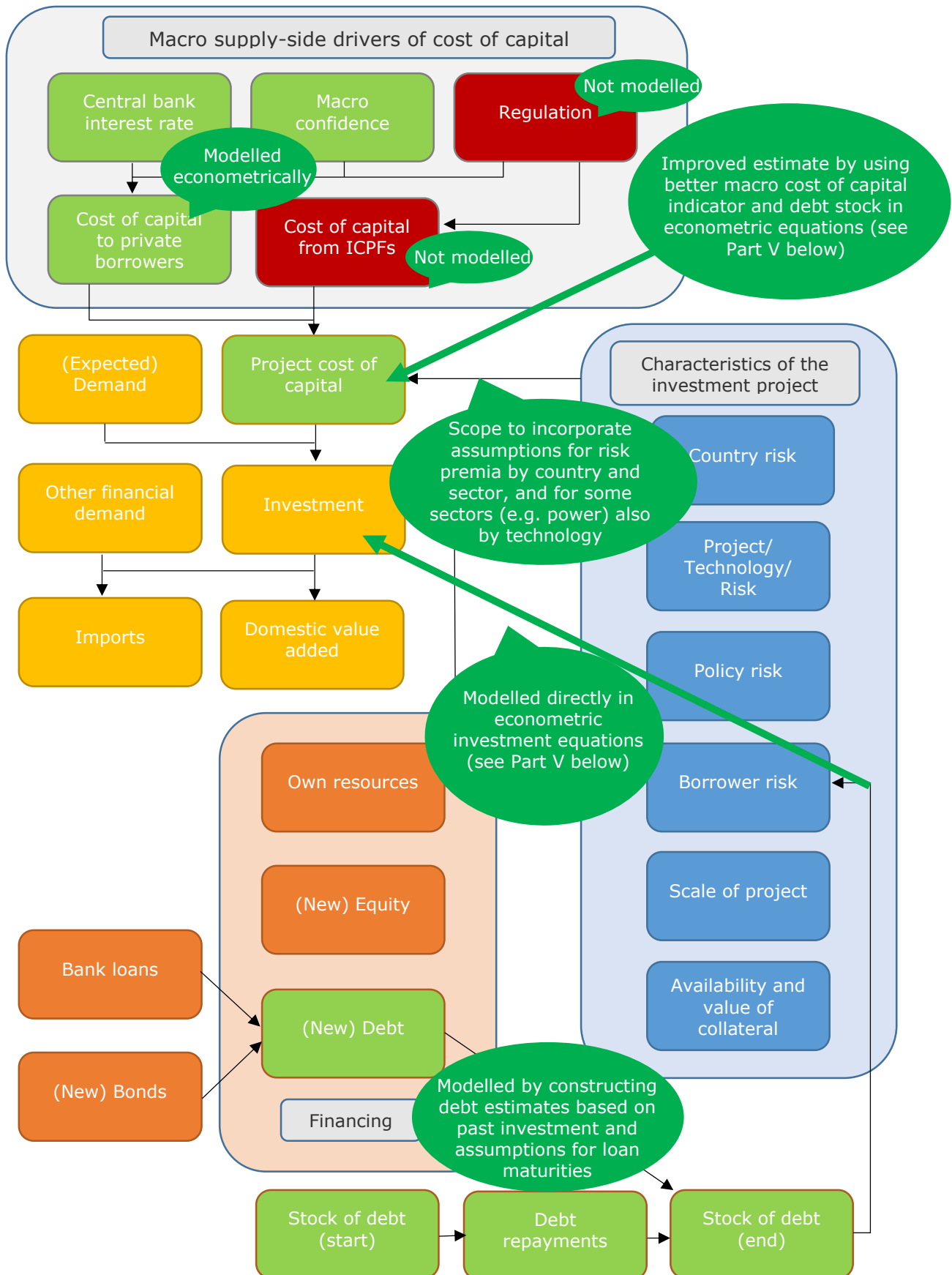
Part IV. Modelling macro confidence effects on the interest rate faced by borrowers

Motivation

In this section we describe the approach taken to implement the improved treatment of the macro supply-side drivers of the cost of capital noted in Figure 2 and Figure 4 and summarised in Part III.

Summary of the approach

E3ME includes the (short-term) policy rate and uses a Taylor rule to determine this, but this is not an appropriate rate to use for decarbonisation investment because:

▪ the rate of interest on loans with a long-term duration differs from the short-term policy rate (usually higher, and less volatile over time in that it does not rise as much when monetary policy is tightened or fall as much when it is relaxed, because long-term inflationary expectations do not change much over the cycle)

▪ the rate of interest on long-term loans to the private sector includes a risk premium which (for the average across all loans) reflects general macroeconomic conditions; this becomes the benchmark for the rate of interest relevant to investment (to which a premium is added that depends on the project/borrower risk characteristics)

We therefore introduce into E3ME:

▪ a low-risk, long-term interest rate (the yield on a safe 10-year bond, which for countries with low sovereign credit risk is well represented by the yield on government bonds), which acts as a benchmark for other long-term rates

▪ an average long-term interest rate for bank loans to, or bonds sold by, the private sector; this rate will be the default rate used for investment equations and it is determined as a spread relative to the low-risk, long-term interest rate

Rationale and evidence

The policy rate and the long-term, low-risk rate

We assume a *liquidity-preference* explanation of the term structure of interest rates: lenders are risk-averse and prefer the flexibility, in the face of uncertainty, offered by short-term maturities; they therefore require a premium to lend for the long term. Borrowers prefer the certainty of a long-term commitment and are willing to pay a premium for this. The result is a rising yield curve (as the maturity length increases). The implication is that an investor strategy of 'buy and hold' delivers a higher return than 'buy short-term and continually roll over', because the latter strategy has the co-benefit of greater liquidity (as a hedge against uncertainty).

However, *expectations* of future (short-term) interest rates also play a part. If (short-term) interest rates are expected to fall in the future, the expected returns on a 'buy short-term and roll over' strategy are less than what would be implied if the present short-term interest rate were assumed to continue indefinitely. The consequence is that if (short-term) interest rates are expected to fall, the gap between the short-term and long-term rates will be lower (compared to the case when short-term interest rates are neither expected to fall nor rise), and in extreme circumstances the gap can be negative (the yield curve becomes inverted). Expectations may change even if the policy rate does not change, for example if

there is a shift in expectations about the long-term inflation rate: lower inflation in the long term will be interpreted as resulting in lower nominal interest rates (for the same real rate).

There is, therefore, a general tendency for a change in the short-term policy rate to affect long-term rates in the same direction, but not by as much (the gap closes when rates rise and opens when rates fall) if the new rate is perceived to be only temporarily high or low. In practice this means that when the policy rate is raised to curb excessive inflation (and an economic boom), the safe long-term rate does not rise by as much (the spread between them falls); when it is cut sharply to mitigate a recession, the safe long-term rate does not fall by as much (the spread rises).

A third factor is the role of *macroeconomic uncertainty*.   When conditions are uncertain, there is a flight to safety (an increase in liquidity preference). This will tend to increase the slope of the yield curve (the spread between short and long-term rates). When confidence is high, the reverse is true[3].

Figure 4 shows the short-term policy rate and the yield on 10-year government bonds (interpreted as the safe benchmark asset) in the euro area (with the German bund representing the relevant government bond), the US, the UK and Japan.

The aggressiveness of monetary policy in response to the boom and subsequent crisis varied across the four areas (the largest changes were in the US, and the smallest in Japan). In all cases, the spread between the policy short-term rate and the long-term safe rate narrowed when the policy rate was increased sharply through 2007 and 2008 and then widened when the policy rate was cut sharply in 2008 and 2009.

However, the behaviour since 2010 varies. In the euro area and to a lesser extent the UK, the policy rate has been very low and yet the spread has narrowed sharply. This may be partly because expectations about future (short-term) interest rates have fallen: the expected timing and speed of a 'return to normal' for the policy rate has been pushed back, so that a significant part of the 10-year period of the bond's maturity is now expected to be a low (policy) rate period. But it also no doubt reflects the impact of quantitative easing (QE) which has succeeded in driving down yields on high quality long-term securities. It is also possible that the mood of uncertainty has eased: GDP growth is stable even if it is slow (this is reflected in an improved 'economic sentiment' confidence indicator), and so investors are less fearful of a sharp fall in asset prices[4].

In the US, the reduction in the spread has been much less pronounced, which may reflect an expectation that the policy rate will be raised sooner (than in Europe). The case of Japan seems to be dominated by the expectation (based on historical experience) of very low or negative inflation.

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[3] It is also the case that greater uncertainty will increase the spread between the rate charged on loans to (or the yield on bonds issued by) institutions whose default risk is not negligible compared with the rate for the benchmark safe asset (normally government bills/bonds), but this is a separate issue discussed in the next section).

[4] Not shown in this chart, the yield spread relative to the German bund for Euro area government bonds that were perceived to be riskier rose in the crisis (most obviously for Greece, but also to a lesser extend for Ireland, Spain and Italy).

*Figure 4: The short-term policy rate and the yield on 10-year government bonds in selected countries*
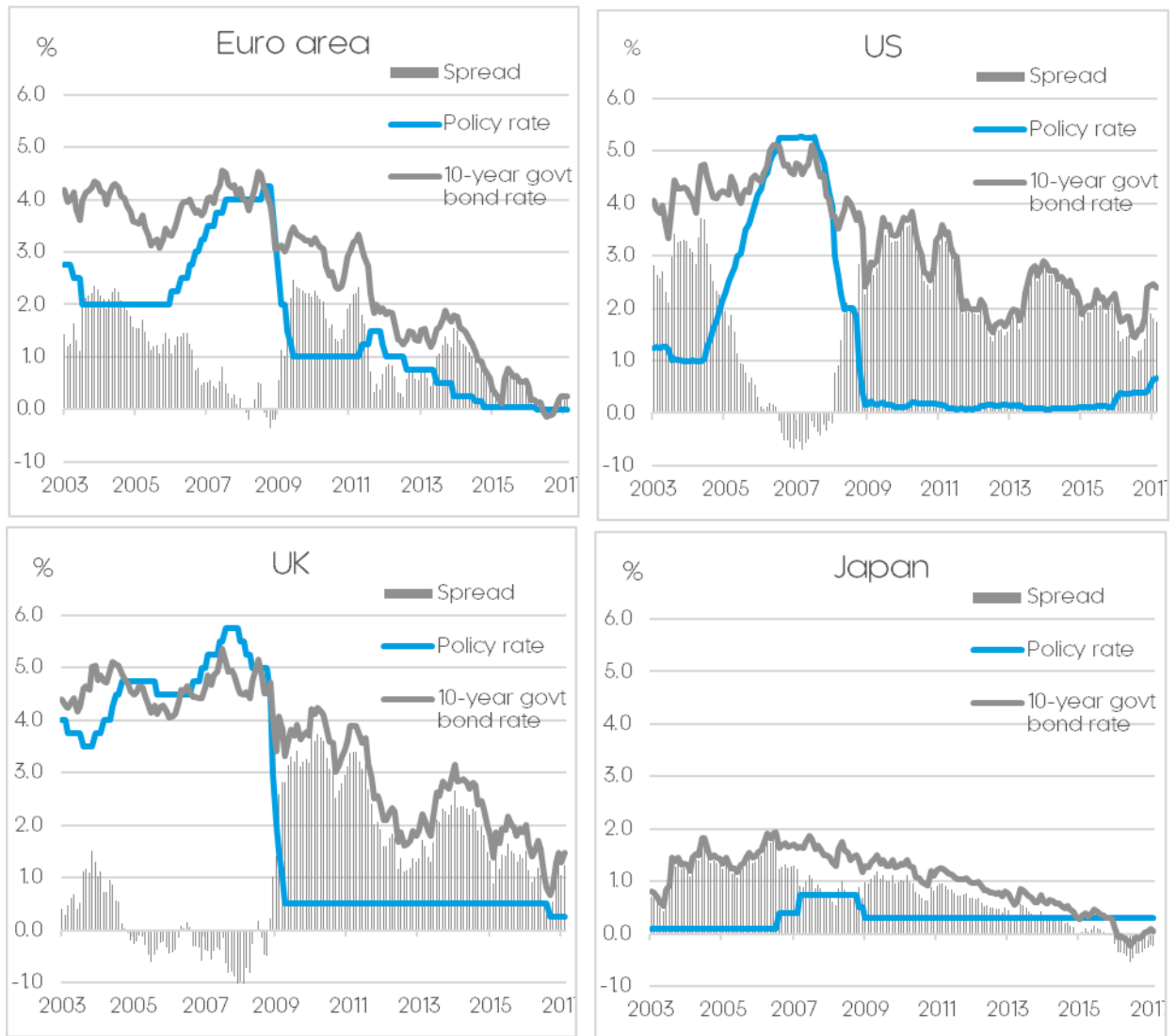
Notes: The 10-year government bond rate for the Euro area is the German bund.
Sources: ECB, Federal Reserve Bank of St Louis (FRED), Bank of England.

The long-term low-risk rate and the rate charged to private borrowers

Because private borrowers (usually) carry a higher default risk than governments, their loans/bonds carry an additional premium, and different borrowers/projects carry different premia depending on the perceived risk (including the availability of collateral to mitigate the lender's risk). But QE can also bring down the yield on lower quality long-term assets as investors respond to a low-interest-rate environment by 'reaching for yield' (i.e. fund managers pursue higher returns by taking on a higher level of risk than the ultimate fund owners intend).

Figure 5 shows that the yield on AAA and BAA bonds in the US has generally followed the downward trend in the yield on government bonds in the period since 2010. It also shows the effect of the flight to safety in 2009, when the spread increased for AAA bonds and even more sharply for BAA bonds.

Figure 5: The spread between commercial bonds of different grades and government bond yields
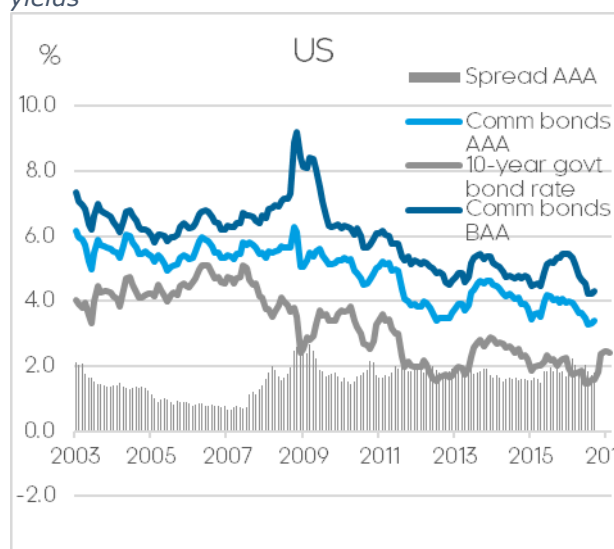

Source: Federal Reserve Bank of St Louis (FRED).

Figure 6 is intended to provide comparable information for the Euro area and the UK, using bank loan rates. However, the long time series is only available for loans of a shorter duration period than the 10 years needed for comparability with the government bond rate. Hence, in the case of the Euro area, the time profile of the commercial loan rate < 1-year is similar to the policy short-term rate. Figure 6 also shows that (for the Euro area, for which we have data) loans with an interest rate fixed for 10 years have a higher rate than those with a rate fixed for up to a year (so, closer to a floating rate loan), reflecting the interest rate risk borne by the lender in the case of the longer fixed-rate period.

In the Euro area, the long-term bank loan rate has followed the government bond yield down. This is not the case for the bank loan rate shown in the UK, which has remained broadly stable.

Figure 6: Bank loan rates and government bond yields in the Euro area and the UK
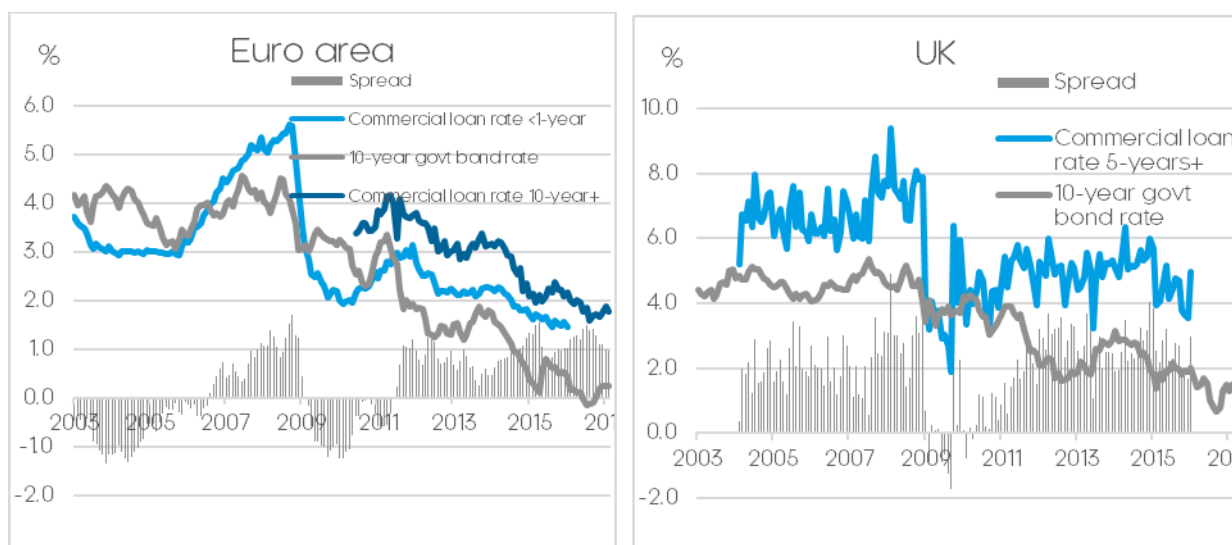
Source: European Central Bank, Bank of England.

Implementation

The long-term risk free rate

Ideally, for each country we would estimate an equation which determines the 10-year government bond yield on the basis of current and lagged values of the short-term policy rate (interpreted as a rule for forming expectations of future short-term rates, and hence a predictor of the 10-year government bond yield, capturing the relationship shown in Figure 4). However, adequate time series data are not available for every country over the long term and, for some countries, the 10-year government bond yield includes a substantial sovereign credit risk element, which we want to exclude at this stage.

The approach taken for the EU is to treat the German bund as the representative long-term risk free rate and to estimate a relationship with current and lagged values of the ECB policy interest rate. This relationship (the extent to which the long-term risk free rate responds to changes in the policy rate) is then assumed to apply to all countries, whether or not they are in the Euro area.

The equation is estimated using the Engle-Granger 2-step method. Estimation results are presented below for the first and second steps.

Dependent Variable: LT_GOVT_DE
Method: Least Squares
Sample (adjusted): 1999 2016
Included observations: 18 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.097053	0.269043	4.077612	0.0009
POLICY_EA	1.001891	0.110538	9.063748	0.0000

R-squared	0.836987	Mean dependent var		3.100040
Adjusted R-squared	0.826798	S.D. dependent var		1.564367
S.E. of regression	0.651050	Akaike info criterion		2.083980
Sum squared resid	6.781867	Schwarz criterion		2.182910
Log likelihood	-16.75582	Hannan-Quinn criter.		2.097621
F-statistic	82.15152	Durbin-Watson stat		1.062817
Prob(F-statistic)	0.000000			

Dependent Variable: D_LT_GOVT_DE
Method: Least Squares (Gauss-Newton / Marquardt steps)
Sample (adjusted): 2000 2016
Included observations: 17 after adjustments
D_LT_GOVT_DE = C(2)*D_POLICY_EA+C(3)*(LT_GOVT_DE(-1)-1.097
    -1.002*POLICY_EA(-1))

	Coefficient	Std. Error	t-Statistic	Prob.
C(2)	0.443012	0.124976	3.544786	0.0029
C(3)	-0.244276	0.177706	-1.374605	0.1894

R-squared	0.229920	Mean dependent var		-0.266176
Adjusted R-squared	0.178581	S.D. dependent var		0.424895
S.E. of regression	0.385091	Akaike info criterion		1.039459
Sum squared resid	2.224430	Schwarz criterion		1.137484
Log likelihood	-6.835398	Hannan-Quinn criter.		1.049202
Durbin-Watson stat	1.736945			

LT_GOVT_DE   German 10-year bund yield
POLICY_EA   ECB short-term policy interest rate
C   Constant (intercept) term
D_   the one-year difference in the variable

The estimated parameters give the resulting dynamic equation the following properties:

- in the short run, a 1 pp change in the ECB policy rate leads to a 0.44 pp change in the 10-year bund yield
- in the long run, a 1 pp change in the ECB policy rate is matched by a 1 pp change in yield on the German 10-year bund

Lags for the ECB policy rate were tried but were not significant. The statistical properties of the equation could no doubt be improved by the inclusion of other variables, but it should be recalled that such other variables would need to be available in E3ME for the equation to be included in the model solution.

The spread to the private commercial rate

The private commercial rate incorporates macroeconomic risk and the average default risk of private borrowers (assumed stable apart from the macroeconomic risk element). We wish to model a rate that is at the lower-risk end of the range, so that we can use it as a benchmark to which we will add an assumed premium for particular project/borrower risk characteristics.

Ideally, for each country we would model the spread (the difference between the private commercial rate and the long-term risk free rate) in relation to current and lagged values of the GDP growth rate (as an indicator of cyclical changes in macroeconomic confidence), capturing the relationship shown in Figure 5 and Figure 6. However, the data available from ECB do not extend back far enough to provide sufficient annual observations. In practice, therefore, it was feasible only to model the spread between the yield on AAA bonds in the US and the 10-year US government bond rate. This relationship (the extent to which the spread varies in response to changes in GDP growth) is then assumed to apply also to EU Member States. In time, sufficient data will be available to replace this with ECB data for bank loans of long maturity to borrowers with collateral (i.e. lower-risk).

The estimated equations for the first and second steps in the Engle-Grange procedure are shown below:

Dependent Variable: COMMSPREAD_US
Method: Least Squares
Sample (adjusted): 1970 2014
Included observations: 45 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.225658	0.133615	9.173041	0.0000
D_L_GDP_US	-5.699944	3.886204	-1.466712	0.1501
D2008	0.794115	0.487226	1.629870	0.1108
D2009	0.604603	0.520981	1.160510	0.2526

R-squared	0.198845	Mean dependent var		1.102048
Adjusted R-squared	0.140224	S.D. dependent var		0.502196
S.E. of regression	0.465657	Akaike info criterion		1.393953
Sum squared resid	8.890295	Schwarz criterion		1.554545
Log likelihood	-27.36393	Hannan-Quinn criter.		1.453820
F-statistic	3.392042	Durbin-Watson stat		0.350209
Prob(F-statistic)	0.026778			

Dependent Variable: D_COMMSPREAD_US
Method: Least Squares (Gauss-Newton / Marquardt steps)
Sample (adjusted): 1972 2014
Included observations: 43 after adjustments
D_COMMSPREAD_US=C(2)*D_D_L_GDP_US+C(3)*D_D_L_GDP_US(
    -1)+C(4)*(COMMSPREAD_US(-1)-1.225658+5.699944
    *D_L_GDP_US(-1)-0.794115*D2008-0.604603*D2009)

	Coefficient	Std. Error	t-Statistic	Prob.
C(2)	-6.095523	1.668715	-3.652825	0.0007
C(3)	-1.971303	1.627889	-1.210957	0.2330
C(4)	-0.195228	0.084129	-2.320594	0.0255

R-squared	0.368443	Mean dependent var		0.009153
Adjusted R-squared	0.336865	S.D. dependent var		0.311369
S.E. of regression	0.253558	Akaike info criterion		0.160764
Sum squared resid	2.571662	Schwarz criterion		0.283639
Log likelihood	-0.456428	Hannan-Quinn criter.		0.206076
Durbin-Watson stat	1.689484			

COMMSPREAD_US	The difference between the 10-year yield on BAA bonds and on 10-year US government bonds
L_GDP_US	The log of US GDP
D2008, D2009	Dummy variables to capture the exceptional impacts of the Great Recession
C	Constant (intercept) term
D_	the one-year difference in the variable
D_D	the one-year difference in difference in the variable

The estimated parameters give the resulting dynamic equation the following properties:

- faster US GDP growth is associated with a closing of the spread between the commercial bond yield and the government bond yield
- an acceleration in US GDP growth in the present and previous years is associated with a closing of the spread

Implications for the enhanced model

By incorporating these equations, E3ME now has an explicit interest rate (country by country) for long-term private borrowing that reflects:

- real-world market conditions (the rate is based on *observed* borrowing rates)
- a theoretically and empirically justified relationship with the short-term policy rate, with plausible parameters
- explicit recognition of the role of macroeconomic confidence factors (so that, for example, a 'low interest rate environment' associated with low-growth, low-inflation conditions does not lead the modelling to underestimate the interest rate faced by private sector, long-term borrowers

This rate is then used as the benchmark to which additional risk premia can be added by assumption to reflect particular risks relevant to decarbonisation investments in particular countries.

Part V. Incorporating the private commercial rate and estimated sector debt in E3ME's investment equations

This section reports the effect of:

- incorporating into E3ME investment equations new variables for the private commercial rate of interest and the estimated level of sector debt
- incorporating the new equations for the private commercial rate of interest and sector investment into E3ME's solution

Estimation results for investment equations

Investment equations are estimated for each investing sector (70 in the EU) and country/region. There are therefore 1,960 such equations for the EU Member States.

The new specification is shown in Figure 9: Impact of assumption of higher borrowing ratio on EU28 all-industry debt

Figure 10: Impact on EU28 investment and GDP of a 30 pp increase in the borrowing ratio for new investment

The results of the third test scenario, in which a sustained 10% shock is applied to investment across the EU28, are shown in Figure 11 and Figure 12. Figure 11 shows that EU28 indebtedness climbs steadily for ten years (the assumed maturity of loans for most sectors) and then levels off. Figure 12 shows that the endogenous outcome for investment is broadly stable at +10% in the old version of the model, but under the new version the higher indebtedness depresses investment initially; in the longer term, the impact of faster macroeconomic growth on investment outweighs the indebtedness effect.

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Inspection of the new estimation results and comparison with the previous version indicates the following effects of including the new indicators:

- the debt variable is generally correctly signed (negative) in both the long-run cointegrating equations and in short-term dynamic impacts with long-run elasticities that lie in the range -0.1 to -2.5 in some 50% of cases
- the (real) commercial interest rate is also almost always correctly signed (negative) and in the majority of cases the elasticity is larger in absolute magnitude than the corresponding term in the previous version of the model
- the impact of the size of estimated parameters for the other variables in the equation is not uniform across countries and sectors, but initial investigations suggest that there is a tendency for parameters to increase in absolute size; a reduction in absolute size and statistical significance would have suggested that inclusion of the new variables had the effect of transferring the explanation of investment from existing variables

Simulation results for investment equations

Initial tests of the new equations were carried out as follows.

1. To test the greater interest rate sensitivity of the new specification, a permanent one-off increase from 2018 in the real rate of interest by 2 percentage points across EU28 (e.g. from 2% to 4%)

2. To test the sensitivity of investment to indebtedness, a permanent increase from 2018 in the amount of investment financed by debt assumption from 50% to 80% for all Member States

3. As a further test of the sensitivity of investment to indebtedness, a permanent 10% upward shock is given to investment across the EU28: in the new version of the model, the endogenous outcome for investment is expected to be less than 10% (as higher debt levels depress investment)

The first test was also carried out in an older model version by adjusting the real long-term interest rate in the investment equation. The previous model version had no impact of indebtedness on investment.

In the first test, an increase in the real interest rate depresses investment in both the old and new versions of the model, but the effect is larger in the new version, reflecting the fact that the new interest rate variable appears to capture better the rate offered by banks to private investors. Since the calculation of commercial rate of interest is now endogenous, the rates rise by a little more than the initial exogenous 2 pp reduction because weaker growth triggered by the lower investment depresses confidence and increases the spread between the commercial rate and the long-term risk-free rate.

Using the new investment specification, Figure 7 shows that the cut in investment by 2030 is approximately 8% in that year (compared to the baseline interest rate case), whereas in the old version of the model the reduction is about 4.7% (Figure 8). The net reduction in GDP in 2030 is 2.6% (compared to the baseline interest rate case); in the old version of the model the reduction is 1.2%.

In the new specification, half of any additional investment is assumed to be funded by borrowing, which affects debt ratios. The results show that the initial cut to investment is moderated in the medium term (2022-2027) due to the lower debt burden. However, once the impact of the initial cut in debt is passed (a maturity of 10 years is assumed for most industries, so approximately 2028), the reduction in investment starts to pick up again. No such effect is present in the simulation using the old version of the model. In a real-world policy simulation, in which the change in policy is less stylised, the impact of indebtedness on investment would be smoother.

Figure 7: Impact on EU28 investment and GDP of 2 pp permanent real interest rate increase, new model specification
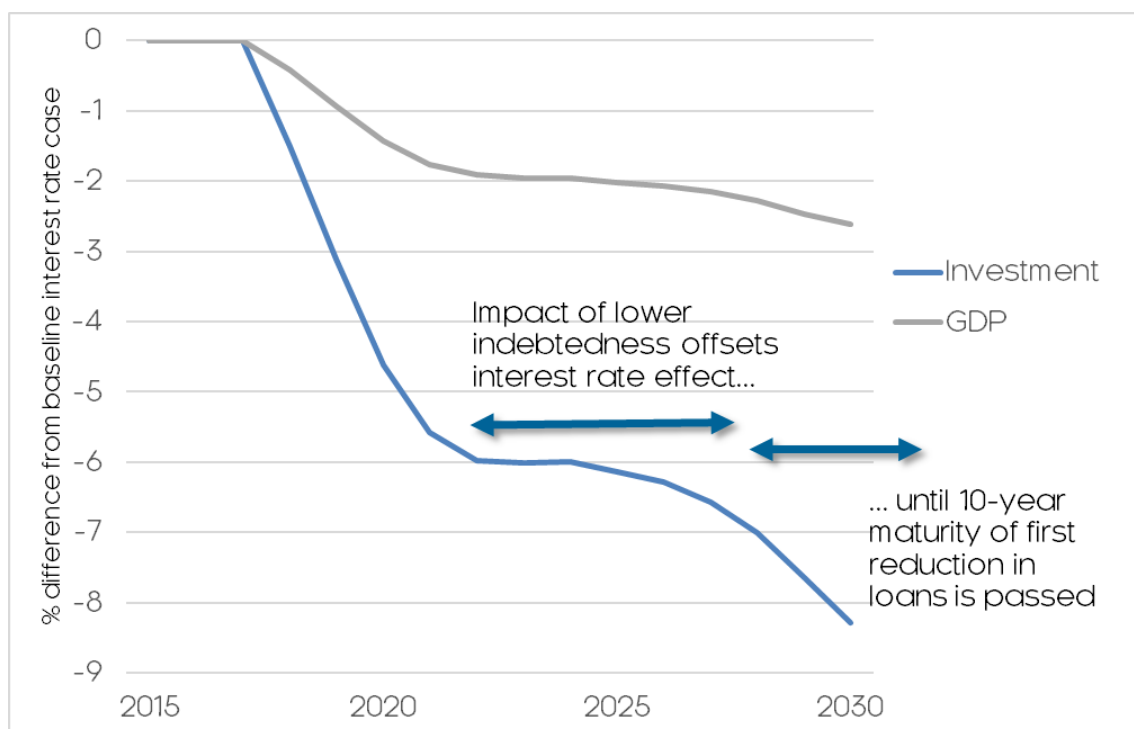
Table 1: Form of the E3ME industrial investment equations

Co-integrating long-term equation:

LN(KR(.))   [investment]

	=	BKR(.,11)	
	+	BKR(.,12) * LN(YR(.))	[real output]
	+	BKR(.,13) * LN(PKR(.)/PYR(.))	[relative price of investment]
	+	BKR(.,14) * LN(YRWC(.))	[real average labour cost]
	+	BKR(.,15) * LN(PQRM(5,.))	[real oil price effect]
	+	BKR(.,16)*LN(DEBT(.)/ (YR(.)*PYR(.)))	[industry debt to output ratio]
	+	ECM	[error]

Dynamic equation:

DLN(KR(.))   [change in investment]

	=	BKR(.,1)	
	+	BKR(.,2) * DLN(YR(.))	[real output]
	+	BKR(.,3) * DLN(PKR(.)/PYR(.))	[relative price of investment]
	+	BKR(.,4) * DLN(YRWC(.))	[real average labour costs]
	+	BKR(.,5) * DLN(PQRM(5,.))	[real oil price effect]
	+	BKR(.,6) * DLN(DEBT(.)/ (YR(.)*PYR(.)))	[industry debt to output ratio]
	+	BKR(.,7) * LN(RCIR)	[real commercial rate of interest]
	+	BKR(.,8) * LN(YYN(.))	[actual/normal output]
	+	BKR(.,9) * DLN(KR)(-1)	[lagged change in investment]
	+	BKR(.,10) * ECM(-1)	[lagged error correction]

Identities:

YRWC	=	(YRLC(.) / PYR(.)) / YREE(.)	[real labour costs]
RCIR	=	1 + (RCRR – DLN(PRSC)) / 100	[real rate of interest]

Restrictions:

BKR(.,2 .,4 .,8 .,12 .,14) >= 0	['right sign']
BKR(.,3 .,6 .,7 .,13 .,16) <= 0	['right sign']
0 > BKR(.,10) > -1	['right sign']

Definitions:

BKR	is a matrix of parameters
KR	is a matrix of investment expenditure for each industry and region, m euro at 2005 prices
YR	is a matrix of gross industry output for each industry and region, m euro at 2005 prices
PYR	is a matrix of industry output price for each industry and region, 2005=1.0, local currency
PKR	is a matrix of industry investment price for each industry and region, 2005=1.0, local currency
PQRM	is a matrix of import prices for each industry and region, 2005=1.0, local currency
DEBT	is a matrix of industry outstanding debt to its output ratio
PRSC	is a vector of consumer price deflator for each region, 2005=1.0
YRLC	is a matrix of wage costs (including social security contributions) for each industry and region, local currency at current prices
YREE	is a matrix of employees for each industry and region, in thousands of persons
RCIR	is a vector of long-run nominal commercial interest rates (long term risk-free rate + commercial spread) for each region
YYN	is a matrix of the ratio of gross output to normal output, for each industry and region

Figure 8: Impact on EU28 investment and GDP of 2 pp permanent real interest rate increase, old model specification
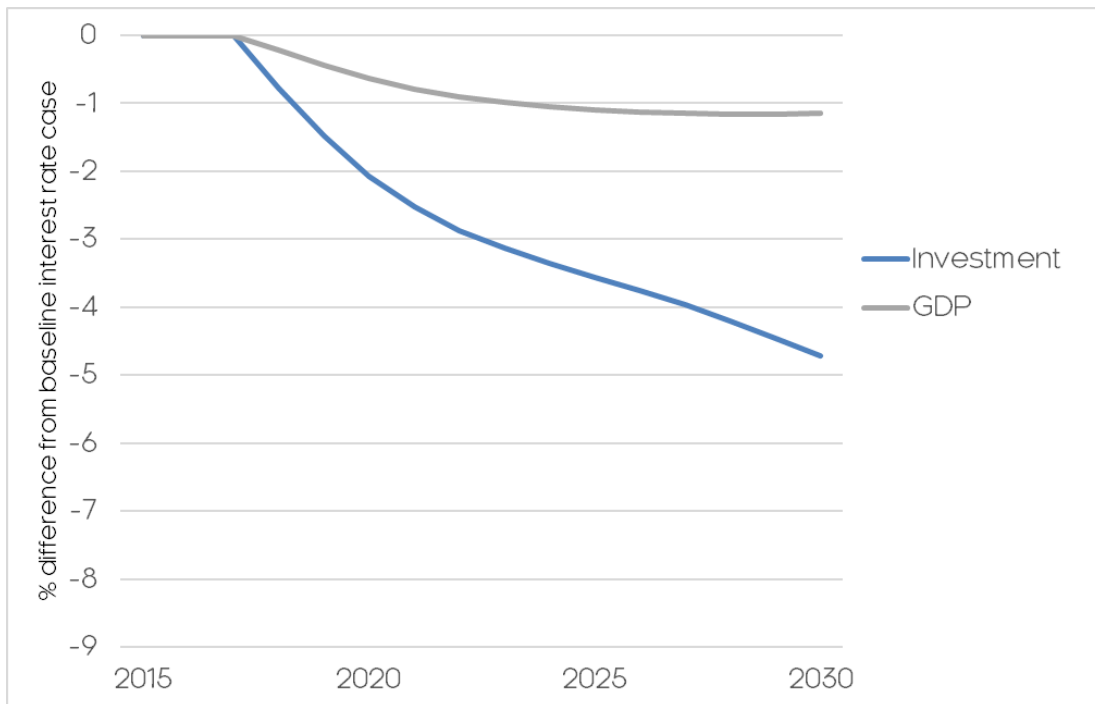
The results from the second test scenario, in which the proportion of investment that is financed by borrowing increases from our standard assumption of 50% to 80%, show negative impacts on investment as expected. The debt burden increases rapidly from 2018 onward (Figure 9) and Figure 10 shows that investment in this scenario is 3.7% lower by 2030 compared to the baseline case of an unchanged borrowing ratio. The investment reduction reaches a trough in 2028 as the first increase in debt in 2018 is paid off by 10 years for most sectors[5]. EU28 GDP in 2030 is around -1.2% below the baseline.

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[5] The standard loan maturity assumption in E3ME is 10 years with the exception of a few sectors in which assets typically have a longer life: power generation, gas, water, manufactured fuels, basic metal and chemicals (for which the loan maturity is assumed to be 20 years.

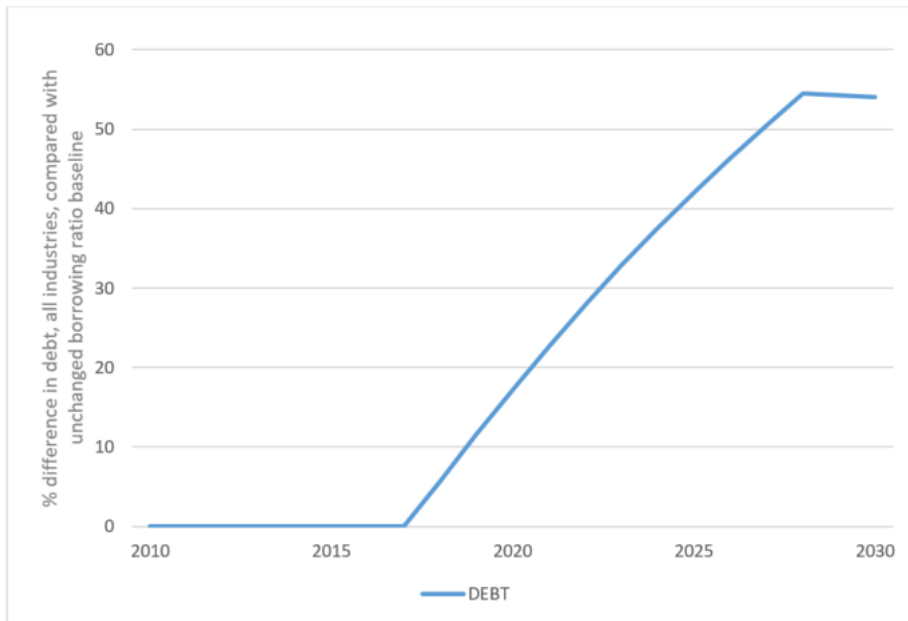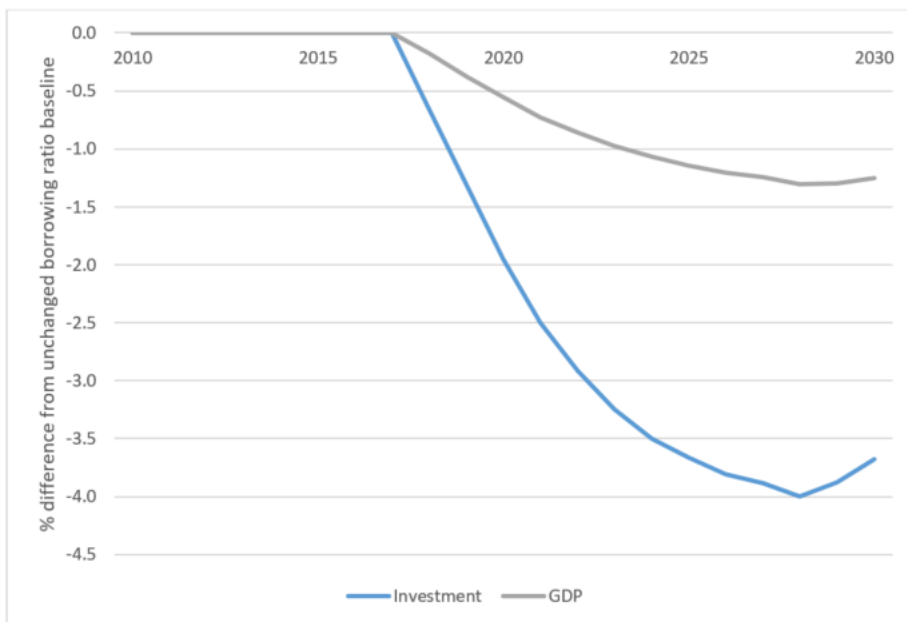*Figure 9: Impact of assumption of higher borrowing ratio on EU28 all-industry debt*

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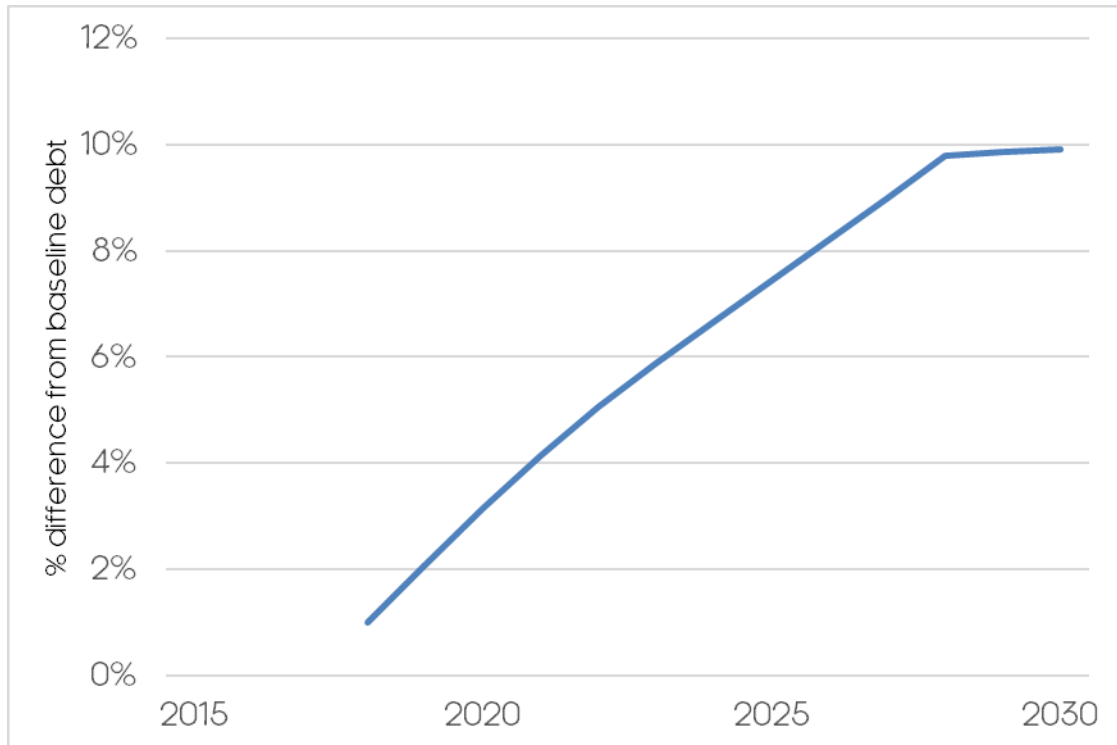*Figure 11: Impact on EU28 indebtedness of sustained 10% upward shock*

Figure 12: Final impact on EU28 investment following sustained 10% upward shock