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BRIEFING

Should ART Be Part of a Population Policy Mix?

A Preliminary Assessment of the
Demographic and Economic
Impact of Assisted Reproductive
Technologies

Jonathan Grant, Stijn Hoorens, Federico Gallo and
Jonathan Cave

Prepared for 22nd Annual Meeting of the European Society of Human
Reproduction and Embryology, held 18–21 June 2006 in Prague

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Preface

This document presents the results of a preliminary study examining the potential role of Assisted Reproductive Technologies (ART) in increasing fertility rates, and mitigating the consequences of population ageing in Europe. The deliverable of this study is a presentation to the Annual Meeting of the European Society of Human Reproduction and Embryology, held 18-21 June 2006 in Prague. This report is a record of that presentation, along with a commentary that allows the reader to delve into the detail of the analysis. The study is funded through a research grant from Ferring Pharmaceuticals.

The study relied on the development of a model to quantify the potential effect of ART treatment on fertility rates and population age structures. On the basis of empirical analysis of the United Kingdom and Denmark, we make a number of initial observations:

1. In 2002, the existing contribution of ART to the total fertility rate (TFR) was 0.02 in the UK and 0.07 in Denmark;
2. If the number of ART cycles per million women in the UK were increased to levels similar to those in Denmark, TFR would increase by 0.04. The total contribution of ART would then be 0.06 children per woman;
3. The potential of ART to contribute to TFR in the UK is comparable to that of other policies used to influence fertility, such as increasing state-supported child benefits;
4. The direct costs associated with the assumed impact of ART on fertility are likely to be less than those of other population policies;
5. Therefore, policies to influence the uptake of ART could be considered part of a population policy mix to increase fertility in Europe;
6. However, if women choose to further postpone childbirth given the prospect of successful ART, the ART contribution to fertility rates could be offset.

It should be stressed that these findings are preliminary and that further work is needed to understand some of the complex interrelationships between the various aspects of policy interventions, reproductive behaviour, and population dynamics.

This report should be of interest to policymakers and researchers who are concerned with the consequences of Europe's low fertility, and the appropriate public policy response. RAND Europe is an independent private, not-for-profit, research institution that helps improve policy and decision-making through research and analysis.¹ For more information about RAND Europe or this document, please contact:

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Summary

If demography is destiny, then it appears that destiny for Europe includes a rapidly ageing population, increasing economic, social and healthcare burdens and a weakening position on the world stage. Governments are waking up to the need to address the demographic shift, but, so far, have not discovered the ideal mix for an effective population policy. This paper provides a preliminary investigation into whether Assisted Reproductive Technologies can play a part in preventing European countries from falling into the low fertility trap.

European governments are concerned because their rates of population growth are decreasing and the sizes of their labour forces are, or soon will be, shrinking. This occurs because people are living longer and having fewer babies. Declining mortality and fertility rates across Europe mean that the older, and especially the retired, members of the population are gradually outnumbering the younger, working population. By 2050, almost one third of Europeans will be over 65 years old, and one in sixteen will be over 85. This demographic shift is extremely worrying because it threatens not only standards of living, but also social and international stability.

Having an older population brings a range of problems, from how to pay the increased pensions bill to who will look after those who need long-term care. Traditionally, those in employment have financed the pensions of the retired, but this model comes under pressure when the size of the retired population grows relative to the working population. The additional health and social care needs associated with older age also add to the economic burden, not least because with shrinking family size, a greater proportion of the workforce will be dedicated to caring for the older population.

While older populations are expensive in economic and social terms, a less obvious but perhaps more noteworthy consideration is the political cost. Because ageing populations are associated with a relative decrease in the number of people working, this has implications for productivity and economic growth. Nations that maintain a young population will have a continuing incoming stream of young labourers in their economy, whereas those with a relatively ageing population may well see a decline in their relative economic importance, which could alter their political standing on the world stage.

Clearly, governments should try to address the issue of ageing populations before the problems outlined above start to take effect. Obviously they are not going to act against the decline in mortality rates, so they must look for other ways to reverse population trends.

An earlier investigation by RAND Europe found various policies aimed at offsetting ageing populations in place across Europe. The three main options are increasing immigration, reforming the welfare state and raising fertility rates.

Increasing immigration will not provide a long-term solution. The sheer number of immigrants needed to compensate for population ageing would be politically unacceptable, and, while immigrants might contribute to the workforce for a while, they too will eventually reach retirement age and become part of the problem rather than part of the solution.

Welfare state reform, such as increasing the retirement age, is high on the agenda for many governments, but will only go some way towards addressing the problem. Continuing financial support is necessary to ensure the existence of the welfare state, and the dependency ratio (the number of people dependent on the working population) is a key figure. If the dependency ratio doubles, then, *ceteris paribus*, the amount required per person to fund the welfare state will be doubled.

The third way to slow down population ageing is to increase fertility rates by encouraging child-bearing.

The total fertility rate (TFR) in every nation in the European Union is now below replacement level, usually taken as 2.1 children per woman. For some countries, it is below 1.5.

Policies such as flexible working, maternity and paternity leave, and increasing benefits for second and third children can affect birth rates by encouraging parents to have more children than they might otherwise have if these policies were not in place. European governments that have introduced policies to make it easier to have and raise children tend to have higher fertility rates than those that do not; nonetheless even these countries have TFRs below replacement level.

One option for governments to address declining fertility rates is to widen the availability of Assisted Reproductive Technologies (ART), such as In-Vitro Fertilisation (IVF), to sub-fertile couples. The impact on TFR of policies aimed at helping couples who are having difficulties conceiving has not yet been assessed – this study starts the process by examining the contribution of ART to fertility rates.

For this study, RAND Europe developed a model incorporating fertility, costs, population age structure and behaviour components, and used data from Denmark and the United Kingdom for 2002.

The number of live ART births in Denmark in 2002 was 4.2% of total live births, whereas in the UK for the same year it was 1.4%. If the number of ART cycles per capita in the UK were increased to the same level as in Denmark, TFR in the UK would increase by 0.04. While this does not sound like much, this rise was found to be equivalent to that achieved by other policy interventions thought to increase fertility. Including ART in a population policy mix may even be more cost-effective than other measures. A comparison of cost per additional birth showed that whereas a 25% increase in child benefits would raise TFR by 0.07, the cost per additional birth was between £50,000 and £100,000. The cost per additional ART birth was estimated at £15,000-£25,000.

While this study demonstrates that policies aimed at increasing the uptake of ART could increase fertility, the authors sound a note of caution. One of the contributors to the decline in fertility rates is that, for various reasons, women are waiting longer to have children. Policies that make ART more widely available and affordable could further

encourage couples to delay starting a family, because they might assume that ART will overcome any fertility problems they may encounter. A woman's natural fertility starts to drop sharply over the age of 35, and older women find it harder to conceive either naturally or with the help of ART. Therefore, the contribution that ART might be expected to make to fertility rates could be offset by the greatly reduced chances of success for older women.

The problems created by ageing populations across Europe need to be addressed. Declining fertility rates are a major contributor to the demographic shift, but it is clear that no single policy will reverse population trends. What this study shows is that ART could be a part of the population policy mix, but that governments need a great deal more information, particularly regarding behavioural responses, before they can design ART policies that will achieve the desired effect.

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Introduction

Should ART be part of a population policy mix?

A preliminary assessment of the demographic and economic
impact of Assisted Reproductive Technologies

Jonathan Grant
with Stijn Hoorens, Federico Gallo and Jonathan Cave

June 2006

Across Europe, birth rates are falling and family sizes are shrinking. The total fertility rate is now less than two children per woman in every nation of the European Union, and 21 of the 25 lowest-fertility countries in the world are in Europe. As a result, by 2050, one in three Europeans will be more than 65 years old, up from one in six in 2000.

These demographic trends threaten future living standards in Europe and low-fertility countries in Asia, including South Korea, Japan, Hong Kong and Singapore. There will be fewer people of working age, and a growing retired population. The anticipated consequences will be manifold. When household sizes decrease, the capacity to care for the elderly in the home diminishes. Also, the demand on health, pension and social security systems increases, while at the same time 'pay as you go' (PAYG) contributions from the workforce to the welfare state decline. And as labour gets scarce, economic growth is expected to decline, along with household wealth.

Concerns over these developments have caused policymakers to take note and begin serious consideration of policy implications and responses.² One strategy that has not been systematically examined is the potential impact of biomedical developments on population ageing. This report presents the results of a preliminary study examining the potential role

² See Grant et al. (2004). *Low fertility and population ageing. Cause, Consequences and Policy Options*. RAND, MG-206; Dixon and Margo (2006). *Population Politics*. London: IPPR; Grant and Hoorens (2006). *The new pronatalism? The policy consequences of population ageing*. Public Policy Research, **13** (1), June 2006.

of Assisted Reproductive Technologies (ART),³ in increasing fertility rates and mitigating the consequences of population ageing in Europe.

³ The term ART refers to different techniques for assisted reproductive treatment, which include, *inter alia*, egg donation (ED) or preimplantation genetic diagnosis/screening (PGD/PGS). In this report, however, we have assumed that ART includes In vitro fertilization (IVF) and Intracytoplasmic Sperm Injection (ICSI) only.

Europe's demographic challenge

A country's age distribution is determined by

Net migration

- EU25 had 17 million net migrants between 1960 and 2002
- Contribution to population change is relatively small

Mortality

- Increasing longevity has been key characteristic of 20th century
- Life expectancy has increased:
 - Males: 43.5 years in 1900 to 75.4 years in 2000
 - Females: 46.0 years in 1900 to 81.4 years in 2000

Fertility

- Reduced family sizes
- Delayed birth of first child

The age distribution or structure of a population is determined by its fertility, mortality and net immigration. Historically, net immigration – that is, the number of immigrants minus the number of emigrants – has been low as a proportion of the overall EU population, typically ranging between -0.2% and +0.3% for the 25 countries that currently make up the European Union (EU25).⁴ Between 1960 and 2002, there have been 16.8 million net migrants into the EU25, equivalent to 3.7% of the EU25 population. The contribution of migration to population change, however, is small when compared to the number of births. Over the same time period, there were 251.7m live births in the EU25, implying that (net) immigrants accounted for 6.3% of the new entrants to the EU25 population over the 42-year period considered.

Declining mortality was one of the defining characteristics of 20th Century. In Europe, life expectancy at birth increased from 43.5 years for males and 46.0 years for females in 1900⁵ to 75.4 for males and 81.4 for females in 2000. Since 1975, mortality risk at almost every age has fallen by a significant amount,⁶ with a resultant increase in life expectancy at birth

⁴ Migration into EU countries displays a wider range because intra-EU migrants appear in these statistics.

⁵ Population-weighted average for EU15 countries. Data sources: Kinsella (1992) "Changes in life expectancy 1900-1990" *American Journal of Clinical Nutrition* **55**: 1196S-1202S; Populstat (www.library.uu.nl/wesp/populstat/populframe.html) [accessed 26 April 2005].

⁶ Ahn et al (2004). *Bio-Demographic Aspects of Population Ageing*. ENEPRI Research Report No. 1, available online at <http://www.enepri.org/Publications/RR01.pdf>.

from 68.4 and 74.7 for males and females respectively in 1970, to 75.4 and 81.4 in 2000, and to a projected 82.3 and 87.4 in 2050.⁷

⁷ Unless otherwise specified, all demographic data come from Eurostat (2006) Population and social conditions database. Available online at <http://www.eu.int/comm/eurostat/> [accessed March 8, 2006].

All European nations are experiencing long-term downward trends in fertility. The Total Fertility Rate (TFR) for a given year is a measure of the number of children that women would have over their life, if at each age they experienced the age-specific fertility rate of that year. A TFR of around 2.1 children per woman is needed to ensure that a cohort of women is replaced by another cohort of the same size in the next generation.

This slide shows that in all countries in the Europe Union TFRs have fallen and are now, in every single country, below the 2.1 children per woman needed for a population to replace itself.⁸ In 2002, of the EU15 Ireland and France had the highest fertility rates of 1.97 and 1.88 respectively, whilst the lowest are in Italy (1.26), Greece (1.27), and Spain (1.27). The United Kingdom's rate of 1.64 is slightly above the EU average of 1.50.⁹ The rate in Denmark was 1.72. In the period 1992-2004, a number of countries – including Austria, Germany, Greece, Italy and Slovenia – have experienced a TFR continuously below 1.5 children per woman.

It is argued that countries with a TFR below 1.5 are locked into a “low fertility trap”.¹⁰ This is when negative population momentum occurs due to the much smaller cohorts

⁸ Source: Council of Europe, Recent Demographic Developments in Europe, Demographic Yearbook, 2003

⁹ It is important to bear in mind that statistics may deviate for different sources. For example, the TFRs for UK produced by Eurostat are different from those by the UK Office for National Statistics. We have chosen 2002 as – at the time of research – this was the most recent year for which all required data were available.

¹⁰ Lutz et al (2003). Europe's population at a turning point. *Science*, 299: 1991-1992; McDonald (2005). *Low Fertility in Singapore. Causes, Consequences and Policies*. Presentation at the Forum on Population and Development in East Asia, May 16-17, Beijing, P.R. China.; Lutz et al (2006). *The “Low Fertility Trap” Hypothesis*. Annual Meeting of Population Association of America, March 30 - April 1, Los Angeles.

born since the mid-1980s entering their reproductive ages. For these countries the number of births will decline further and more rapidly than to date. Thus far, no country's TFR has ever recovered after dropping below 1.5, meaning that a small increase or stabilisation of total fertility could prevent countries like the United Kingdom (1.64) or the Denmark (1.72) from falling into the hypothetical low fertility trap.

Changes in fertility rates have a significant influence on population age structures. In populations where fertility rates are increasing, the number of newborns relative to the number of women in reproductive age rises year-on-year, and in time this will mean that there are more young people in the population than old people. Conversely, in populations where fertility rates are declining the effects will narrow the base of a population pyramid so that, in time, there will be more old people than young people and the population as a whole is considered to have aged. This is illustrated in the slide, which shows the population age structures for the EU15 in 1965 and 2000, and a projected structure for 2050.

Each bar in the population age structure represents the number of individuals in each 5-year age band, with males on the left of the pyramid and females on the right. The salient observation to be made from these three population age structures is the impact of declining fertility. Data for the population pyramids in 2050 is from Eurostat's baseline projection. From the 2002 TFR of 1.50, rates are projected to rise to 1.61 by 2050. Life expectancy at birth is also projected to increase from 75.4 and 82.3 to 81.4 and 87.4 for males and females respectively. The EU15 countries are predicted to receive 42.0m net migrants between 2000 and 2050. As consequence of these demographic changes, the proportion of the population that is over 65 increased from 12% in 1965 to 16% in 2000, and is projected to increase to 30% in 2050. The proportion of the population over 85 is projected to increase from 0.5% in 1965 to 6.0% in 2050.

An alternative way of illustrating the impact of the changing population age structure is through the old-age dependency ratio, as illustrated in this slide for 1970 to 2050. The old-age dependency ratio is the number of old-age people (age 65 or older) to the working-age population (between 16-64 years). Note that this is just a means of representing the economic pressure on the welfare state, since people in the working-age population are not necessarily economically active.

The old-age dependency ratio showed a modest increase between 1970 and 2000, but is predicted to increase further over the next fifty years. This arises first because large cohorts are approaching retirement (the 'baby boomers'), increasing the numbers of people of retirement age, and second because low fertility rates imply that one generation is not being replaced with equivalent numbers of the next. In all but four of the EU25 countries, the working-age population (those aged 16-64) is predicted to fall between 2030 and 2050. The effect of low fertility on the evolution of the dependency ratio is shown most strongly in the cases of Spain and Italy; by 2050, both countries will have more than 65 persons aged 65 or older for every 100 persons of working age.

These new demographics may threaten living standards ...

- Falling productivity and increasing dependency will reduce potential GDP growth from 2.1% to 1.3% a year
- Age-related spending as a proportion of GDP will increase:
 - Pensions: 7.4% (2000) to 10.8% (2050)
 - Healthcare: 6.0% (2000) to 9.3% (2050)
- As a consequence of ageing, share of EU in global output is expected to decrease:
 - EU from 18% (2000) to 10% (2050)
 - US from 23% (2000) to 26% (2050)

The ageing of Europe's population could have far-reaching economic and social effects over the coming decades. A series of EU studies have projected a population ageing-related slowdown in the growth of GDP per capita over the next 50 years.¹¹ The forecasted average fall of 0.4% GDP per capita growth is assumed to come primarily from falling productivity and increasing dependency ratios, which will cut potential GDP growth from the present rate of 2.1% a year to 1.3%.

At the same time that GDP growth is projected to fall, the OECD estimates that age-related public spending will need to increase from 17% of GDP in 2000 to 22% in 2050.¹² To offset this potential decline in the standard of living, productivity rates will need to increase. However, the literature on whether population ageing will negatively or positively impact on productivity and technology change is ambiguous. One school of thought argues that an ageing labour force will be less dynamic, creative and innovative. An alternative is that scarcity in labour will prompt capital deepening, leading to productivity gains and increased economic growth.¹³

¹¹ For further details, see Grant and Hoorens (2006).

¹² Dang et al. (2001). "Fiscal Implications of Ageing: Projections of Age-Related Spending", OECD Economics Department Working Papers, No. 305, OECD Publishing.

¹³ For a detailed discussion of the relation between population age structure and economic growth, see: Bloom, et al. (2002) *The Demographic Dividend: A New Perspective on the Economic Consequences of Population Change*. MR-1274-WFHF, RAND Corporation, Santa Monica.

A further impact of population ageing is on the distribution of global output. International comparisons project similar output growth for Japan and Europe, but not for the United States, where growth rates of 2% are predicted over the next 50 years. This means that the EU's present share of 18% of world production is predicted to fall to 10% as a consequence of population ageing, compared to a rise from 23% to 26% for the US.¹⁴ The relative economic importance of the EU and its states may diminish, compared to other countries. This will begin to affect the nature and strengths of relationships between different nation states and the whole dynamic of international diplomacy.

¹⁴ DG ECFIN (2002). *The EU Economy: 2002*. Luxembourg: Office for Official Publications of the EC.

Concerns over population ageing and its predicted economic impact have caused policymakers to begin serious consideration of policy implications and responses. The engagement of governments in ‘population policy’ has historically had a bad press, often being associated with the eugenics of Nazi Germany and China’s one child policy.¹⁵ Recently, European governments have woken up to the challenges of an ageing population and they are, albeit tentatively, beginning to debate the issue.

For example, as reported in *Time* magazine in 2004, the French President, Jacques Chirac, has argued that the European Union needs to “take new action to sustain Europe’s demography and better reconcile professional, personal and family life with the aim of permitting couples to have as many babies as they want”.¹⁶ European politicians increasingly echo these sentiments, although there is still some nervousness about pursuing an explicit population policy as illustrated by (then) UK Trade and Industry Secretary Alan Johnson’s response to a question about whether the Work and Families bill would increase fertility: “This is not ‘breed our way’ to economic success. This is a very British work and families bill and a very British approach”.¹⁷

The captions in the slide above illustrate how this debate is being reported around the world. They show that whilst population policy may have a bad press, it actually makes good press. Perhaps the most important conclusion to draw from this reporting is that the

¹⁵ *Op cit.* Dixon and Margo (2006).

¹⁶ Graff (2004). We need more babies! *Time Europe*, November 21st 2004.

¹⁷ As cited in Dixon and Margo (2006), *Op cit.*

old adage that “demography is destiny” is being tested and there is a demand for informed policy responses to the challenges posed by ageing.¹⁸

¹⁸ Wilson (2006). The Century ahead. Daedalus, Winter 2006.

Governments can respond to this challenge

- Three broad strategies have been considered
 - Increased immigration of working-age people
 - Reform the welfare state
 - Encourage more childbearing
- RAND Europe 2004 report reviewed policy responses and effects
 - Replacement migration cannot prevent population ageing
 - Governments can influence fertility rates under right circumstances
 - There is no silver bullet: a policy mix is required
 - The political, economic and social context influences fertility change
 - Population policies take effect slowly, and may be politically unattractive

RAND Europe undertook a European Union funded study to help inform policy and decision-making that analysed the relationships between European government policies and demographic trends and behaviour, and assessed which policies can prevent or mitigate the adverse consequences of current low fertility and population ageing.¹⁹ This review demonstrated that governments of low-fertility countries have experimented with three broad strategies, which have been of limited success:

1. The effectiveness of allowing large numbers of working-age immigrants has been subject to debate, as the sheer number of immigrants needed to offset population ageing is likely to be politically unacceptable and, over the longer term, immigrants themselves age.²⁰
2. Attempts to influence childbearing have been more successful – countries that invest in policies to make it easier to have and raise children (e.g. Sweden) tend to have higher fertility rates than those who do not (e.g. Spain). For example, in recent decades France has employed a suite of policies intended to achieve two goals:

¹⁹ *Op cit*, Grant et al. (2004).

²⁰ For a more elaborate discussion of migration as a counter to population ageing, see: UNPD (United Nations Population Division) (2000). Replacement Migration: is it a solution to declining and ageing populations? Department of Economic and Social Affairs, Population Division, Geneva and New York: United Nations; Mitra (1990). Immigration, below-replacement fertility, and long-term national population trends. *Demography*, 27(1), 121-129; Le Bras (1991). Demographic impact of post-war migration in selected OECD countries, in *Migration. The demographic aspects* pp. 15-26. Paris: Organisation for Economic Co-operation on Development; Lesthaeghe *et al.* (1988). Are immigrants substitutes for births? Inter-university Programme in Demography, working paper 1988-3. Brussels: Inter-university.

reconciling family life with work and reversing declining fertility. Therefore, France instituted generous child-care subsidies and particularly rewarded families for having at least three children. Sweden, by contrast, reversed the fertility declines it experienced in the 1970s through a different mix of policies, none of which specifically had the objective of raising fertility. Its parental work policies during the 1980s allowed many women to raise children while remaining in the workforce. The mechanisms for doing so were flexible work schedules, quality child care, and extensive parental leave on reasonable economic terms. Despite these generous measures, Sweden's fertility dropped again during the 1990s to an all-time low in 1999.

3. The third strategy of welfare reform is an ongoing process in much of Europe. Across Europe health care systems are reformed, pension benefits rationed and pension ages increased. However, this will only go some way to address the problem; if the number of people who are dependent on the working population doubles (as predicted between 2000 and 2050), then in effect we will need to see reforms that will halve the welfare state. Curbing the welfare state will require political leadership given that retiring baby-boomers will become an increasingly powerful electorate.

However, one strategy that has not been systematically examined is the potential impact of biomedical developments on population ageing, such as fertility treatment; in other words, the effectiveness of formulating policies which aid those people who would like to have children but cannot because of infertility.

Why ART could be relevant in this debate

- Other strategies have not been able to reverse fertility trends
- A mix of policies is required
- An increasing number of countries are entering the low fertility trap
 - No records of countries recovering from TFR below 1.5
 - Preventing countries from dropping below 1.5
- Although the impact of ART is not likely to be large, small changes could be crucial
- Some countries have introduced IVF reimbursement with the aim to offset low fertility
 - Korea & Estonia recently announced IVF reimbursement with explicit aim to increase fertility

A *prima facie* case can be made for including fertility treatment as part of a ‘population policy mix’ aimed at increasing fertility rates. The WHO estimates that some 60-80 million couples worldwide require medical help to conceive,²¹ whereas at least a quarter of couples experience a period of infertility (inability to conceive) lasting over 1 year.²² Furthermore, the prevalence of sub-fertility – i.e. the inability to conceive after a year of unprotected intercourse – increases with age; in their twenties, approximately 5% of all women are sub-fertile, while this increases to nearly 100% around the age of 50.²³ Fertility treatment provides reproductive assistance to those people who would like to have children but cannot because of infertility. ART treatment typically include *in vitro* fertilisation (IVF), intra cytoplasmic sperm injection, frozen embryo replacement (FER), egg donation (ED), preimplantation genetic diagnosis/screening (PGD/PGS) and *in vitro* maturation (IVM). In 2002 there were 668,777 babies born in the UK, 9443 (1.4%) of these were born as a result of ART,²⁴ an increase of 0.3% compared to 2000.²⁵

²¹ WHO (1997). *Progress in reproductive health*. World Health Organisation. [www.who.int/reproductive-health/hrp/progress/42/prog42.pdf]

²² Gunnell et al (1994). Infertility prevalence, needs assessment and purchasing. *Journal of Public Health Medicine*, **16**: 29-36.

²³ More detailed information about prevalence of sub-fertility is provided in section A1 of Appendix A.

²⁴ Nyboe Andersen, Gianaroli, Felberbaum, de Mouzon and Nygren (2006). Assisted reproductive technology in Europe, 2002. Results generated from European registers by ESHRE. *Human Reproduction*, April 3, e-pub ahead of print, 1-18.

As noted earlier, there is no magic bullet: whilst governments can and have had an impact on fertility, no single policy intervention has been a guarantee for success. Historically, governments have attempted to boost fertility through a mix of policies and programmes, with individual interventions having relatively small effects. Although the impact of ART on fertility rates is likely to be small, these changes may be comparable with other interventions. Moreover, for those countries with a TFR just above 1.5, a small increase in fertility may prevent them from entering into the 'low fertility trap' described earlier.

For example, Korea has announced that about 16,000 childless couples will be provided with half the cost of IVF treatment in 2006 with the explicit aim of increasing fertility rates.²⁶ In addition, it was announced in 2006 that Estonia would be introducing subsidised IVF treatment with the explicit aim of increase fertility.²⁷

However, the effectiveness of ART within the population policy mix needs to be evaluated before it can be advocated as an intervention to increase Europe's low fertility.

²⁵ HFEA (2000). *Ninth Annual Report & Accounts*; Nyboe Andersen and Nygren (2004). Assisted reproductive technology in Europe, 2000. Results generated from Europe registers by ESHRE. *Human Reproduction*, **19**: 490-503.

²⁶ Korea Herald (2006). *Daring population policy*. March 8, 2006.

²⁷ 'Red fades to grey', *The Economist*, May 27th, 2006.

Assessing the impact of ART

To quantify the potential effect of ART on fertility rates, population age structures and the economy, we developed a model based on the schema illustrated in this slide. A detailed model description, including assumptions and data sources, is provided in Appendix A.

The model has four components. In the middle of the model diagram is the fertility component that describes the relationship between fertility rates and ART and derives assisted and unassisted age-specific fertility rates. In addition, the fertility component also computes a maximum fertility rate, which assumes that all sub-fertile women achieve the fertility rate of fertile women.

The impact of assisted births is then examined in the population age structure component. This allows us to project the impact of ART on the population age structure in 2050. The third component then relates the impact of the population age structure on economic indicators. In this preliminary phase, we have only included the old-age dependency ratio.

The fourth element of the model is the behavioural component. Behaviour influencing choices related to family formation include for example: marriage, sexual activity, contraceptive use, and abortion. Behaviour related to assisted reproductive treatment could include the willingness to pay for IVF cycles or timing of births. This is discussed in more depth later and would be the basis of any ongoing work. In this component we consider

the consequences of some of the implicit assumptions that are in our empirical analysis.²⁸ This includes, by means of illustration, the assumption that assisted and unassisted fertility are independent when, in practice, fertile couples may deliberately postpone (unassisted) fertility in the knowledge that they could resort to ART at a later date.

Finally, we are interested in factors that influence micro-economic choices related to assisted and unassisted reproductive behaviour. First, government policies, such as reimbursement of IVF cycles, could influence individual behaviour. Secondly, exogenous factors beyond the control of policy makers may play a role in both the prevalence of subfertility (e.g. the uncertainty of decreasing semen quality due to, for example, cellular phone radiation)²⁹, and decisions related to ART treatment (e.g. reduced costs of ART due to medical progress).

²⁸ The grey arrows in the figure indicate the areas of future or ongoing work, which are not (explicitly) addressed in this preliminary study.

²⁹ See for example: Derias *et al.* (2006). Growing concern over the safety of using mobile phones and male fertility. *Archives of Andrology*, **52** (1): 9-14; Fejes *et al.* (2005). Is there a relationship between cell phone use and semen quality? *Archives of Andrology*, **51** (5): 385-393; Aitken *et al.* (2004). Seeds of concern. *Nature*, **432**: 48-52.

Two cases: United Kingdom and Denmark

Population	59.3 million
TFR:	1.64
ART cycles	37,083
ART births:	1.4% of total births
Life expectancy	76.1 yr (M)/ 81.1 yr (F)
Age of 1 st birth	29.1 years (F)
Current policy	Regional variations in reimbursement policies

Population	5.4 million
TFR:	1.72
ART cycles	11,081
ART births	4.2% of total births
Life expectancy	75.5 yr (M)/ 80.2 yr (F)
Age of 1 st birth	27.5 years (F)
Current policy	3 cycles reimbursed in public clinics

To assess the empirical impact of ART on fertility rates, population age structures and the economy, we used data for two countries - the UK and Denmark (DK). It is worth reminding the reader of the preliminary nature of this analysis, and to note our intention – once the model is fully developed – to run data for a range of other countries with differing demographic profiles and policies at different points in time.

As illustrated in this slide, we chose the UK and Denmark because they had similar demographic profiles and, in particular, fertility rates. At 1.64, the TFR of the UK (2002) was slightly lower than that of Denmark (1.72).³⁰ Other demographic indicators are comparable as well, such as the female age at first childbirth (29.1 years and 27.5 respectively), which is, arguably, one of the main drivers of low fertility. Furthermore, the differences in life expectancy – as explained, the other key driver of population ageing – of the two countries are small. Women in the UK have undergone a total of 38,083 ART cycles, resulting in a number of ART births accounting for 1.4% of all live births in 2002. In Denmark, however, this percentage was nearly three times as high.³¹

A further, practical, reason for choosing the two countries was the availability of data, which is referenced in detail in Appendix A. We have used a dataset of 2002, because data from both Denmark and the UK were available for that year. This included disaggregated age-specific fertility on 5-year age groups.

³⁰ Provisional fertility rates for 2005 give an average number of 1.80 children per woman in England and Wales. This is the fourth consecutive annual increase from a low point in 2001. Source: Office for National Statistics (2005). Available at: <http://www.statistics.gov.uk>. Accessed on: May 22nd, 2006.

³¹ Recent data suggest that this percentage in Denmark is still increasing.

This slide illustrates age-specific fertility rates (ASFR) and total fertility rates (TFR) for the UK and Denmark under three scenarios of assisted reproduction uptake.³²

The lowest (green) line assumes that there are no births resulting from ART ($ASFR_u$ in the annotation used in Appendix A). This is calculated by deducting assisted age-specific fertility rates from the observed age-specific fertility rate ($ASFR_o$). In other words, this removes the current 1.4% of births in the UK and 4.2% of births in Denmark that occur following fertility treatment.

For Denmark, the middle (black) line is observed fertility ($ASFR_o$), which includes the current 4.2% of ART births. For the UK we have projected a ‘most likely’ $ASFR_{DK}$ (red line) by assuming that the UK increases the number of ART cycles from the current 37,083 (i.e. 625 cycles per million women) to 109,680. The latter is calculated using the 11,321 cycles in Denmark, corresponding to 2,106 cycles per million women.

The top (purple) line – $ASFR_m$ – assumes that all sub-fertile women adopt the fertility of fertile women and thus provides maximum level of fertility that could be achieved through ART. The figures underneath the graphs summarise the consequences of these scenarios for Total Fertility Rates.

A number of key observations can be made from this analysis. First, if access to ART in the UK were increased from the current 625 cycles per million women to the 2,106 cycles per million women in Denmark, the TFR would increase by 0.04, from 1.64 to 1.68. Conversely, if Denmark ceased to use ART then the TFR would decrease by 0.07, from

³² The calculations and data sources supporting these results are discussed in Section A1 of Appendix A.

1.72 to 1.65. Secondly, the maximum impact of ART – that is, the difference between unassisted total fertility (TFR_u) and maximum total fertility (TFR_m) – would be 0.22 in the UK and 0.24 in Denmark, and this provides an upper-bound estimate for the fertility impact of ART.

The slide pictured above illustrates the consequences of an increase in the number of ART births for the population age structure. It depicts the situation in the UK in 2050 when the first additional ART births have reached age 46. The red and blue margins indicate the additional proportion of the male and female population that could be born through ART following an increased uptake of ART in the UK. These correspond to the difference between the black and red line in the previous figure.

The increased number of ART births will not have an impact on the size of the labour population until 15 years from now. In fact, the dependency ratio will first increase before these additional people born because of ART reach working age, and the economic dependency ratio will increase due to the larger proportion of young dependents receiving education and health care. As soon as these additional men and women born through ART begin entering the labour force population, they will contribute to reducing the ratio of old-age dependents to the working-age population.³³

This impact on the dependency ratio is, however, relatively small. If access to ART in the UK were increased from the current 625 cycles per million women to the 2,106 cycles per million women in Denmark, the cumulative effect on the old-age dependency ratio in 2050 would be a 1.7% decrease. It must be noted that, when the additional ART population start to retire, they will contribute to further increasing the old-age dependency ratio.

Further research is needed on the consequences ART births on age-related spending.

³³ And if ART continues to be practiced, it will increase the number of young dependents even after additional people born because of ART reach working age.

A small effect, but comparable to other policies

- ART births in UK:
 - The total contribution of ART to the TFR would increase from 0.02 to 0.06
 - Costs estimated between £250m and £430m per annum for UK
 - Between £15k and £25k per additional ART birth
- Child benefits in 22 OECD countries (Gauthier & Hatzius, 1997):
 - 25% child benefits increase lead to 0.07 TFR increase
 - Costs estimated between £1.5bn and £2.5bn per annum for UK (2006)
 - Between £50k and £100k per additional birth
 - Acknowledge that child benefits yield other positive benefits
- Other studies report similar impacts

The previous slides illustrated that the effect of ART on TFR and the overall population age structure is relatively small. Even under optimistic scenarios, an increase in the uptake of ART will not bring the TFR in the UK above replacement level.³⁴ However, when comparing with other population policy measures that are thought to influence childbearing behaviour; the order of magnitude of the impacts is similar.

Gauthier and Hatzius (1997) modelled the relationship between policies and fertility for 22 OECD countries between 1970 and 1990. They concluded that a 25% increase of child benefits expenditure would have a positive effect on TFR of 0.07 in the long term.³⁵ In the UK, a 25% increase in child benefit would correspond to an amount between £1.5 and £2.5 billion per annum. That is around £50,000 and £100,000 per additional birth.

We estimate the costs associated with the TFR increase due to ART births to be between £250 and £430 million per annum. This is based on an average cost per IVF cycle of £2,771.³⁶ These costs depend on the criteria for inclusion of different age groups, as the

³⁴ Although it should be noted that the proportion of couples who have difficulties conceiving within 2 years is expected to increase. The potential demographic effect of ART could therefore be larger in future.

³⁵ Other studies claim similar impacts, see: Gauthier (2001). The Impact of Public Policies on Families and Demographic Behaviour. Paper presented at the ESF/EUESCO conference 'The second demographic transition in Europe' (Bad Herrenalb, Germany 23-28 June 2001).

³⁶ National collaborating centre for women's and children's health. (2003) *Fertility guideline: assessment and treatment for people with fertility problems*. Available at: www.nice.org.uk/pdf/CG011niceguideline.pdf. Accessed on: April 21, 2006

success rate decreases considerably with age.³⁷ Across ages, the success rate of IVF is on average around 15%. Based on these calculations, the costs per ART birth are estimated between £15,000 and £25,000.

This preliminary comparison illustrates that the impact of ART on TFR is similar to that of other population policy measures. Additionally, including ART in the population policy mix may be more cost-effective than conventional family policies. We must acknowledge however, that policy measures such as child allowances or public childcare benefit all babies and not just the additional ones, and have policy aims that go beyond that of increasing fertility, such as improving children's well-being.

³⁷ The success rates per age group are given in Section A2 of Appendix A. The total costs of ART treatment to women up to age 39 (TFR impact: 0.037) would be £259 million, while the total costs of ART treatment to women of all ages (TFR impact: 0.042) would be £427 million.

These results are preliminary

Main assumptions

- Only female infertility considered (no male or couples)
- Birth orders are neglected and ART babies are identical to non-ART babies
- Data for ART is made up of IVF and ICSI data only
- Fertility and mortality are constant with time, and migration is neglected
- No changes in technology in future

Main caveats

- Data quality on sub-fertility needs to be improved
- No behavioural effects

As noted in the introduction, this is a preliminary study that sets out to test the hypothesis that ART could be considered as a population policy with the aim of increasing fertility rates in Europe (and elsewhere). The findings we have presented are first estimates and are based on a number of assumptions that need to be tested and improved in subsequent work.

We have assumed that a couple's ability to conceive is largely dependent on the woman's age. A more accurate study could incorporate the effects of the male's age as well. As far as births are concerned, no distinctions between different birth orders have been made, and the number of births is equally divided between males and females. Also, ART babies are assumed to be identical (biologically and from a socio-economic point of view) to non-ART babies.

In the population dynamics model, fertility and mortality are assumed to be constant over time, with their values the same as those in 2002, and migration is neglected. Also, the model is deterministic, and therefore does not include elements of uncertainty.

It is worth noting that over the next decades, new technologies may be developed to deal with infertility and subfertility. Within the scope of this preliminary study, however, we have assumed that this is not the case.

Although ART includes multiple techniques, we have only included data on births through IVF and ICSI, as these treatment methods constitute the majority of births through ART treatments.

The quality of the data underlying the models could be improved in a number of ways. In particular, the data on the age-specific proportion of sub-fertile couples varies across

different sources, and there seems to be no universally accepted figures. This is due to inconsistent definitions, and measurement difficulties.

The empirical models do not include behavioural components. For this reason the ‘tempo effects’ (effects related to the timing of childbirth) are only preliminary. An initial behavioural model has been developed to begin to address this issue, but this is still at an early theoretical stage; however, this represents a solid base for further research.

The assumptions made in the model are described in more detail in Appendix A.

An ART policy has wider (un)intended consequences

- Improved quality of life due to ART
- Possible further delay of family formation
 - Counteractive tempo-effects may lead to more rapid ageing
 - Followed by a rapid rejuvenation after several decades
- Health effects of delay
- Effects on household income are larger for economically disadvantaged couples
- Multiple births and other potential health effects of ART
-
-

We have shown that there is an argument for including ART in a population policy mix. However, the consequences of ART are not restricted to the population dynamics. A first intended impact of ART is that the quality of life of parents who had successfully undergone ART treatment will improve substantially.³⁸ Other intended and unintended effects have not been addressed in this study, although they are crucial for future recommendations to governments. Aside from unanticipated demographic consequences, the effects may include social-cultural, economic, ethical, political, and clinical issues, and those related to public health.

For example, if women choose to (further) postpone childbirth based on the prospect of successful ART treatment, then it may actually have a negative effect on the TFR and consequently lead to further ageing of the population. Following this period of delay, there could be a period of rejuvenation. Another side-effect of older ages of childbearing is the increased risk of birth defects (e.g. Down syndrome). Because of these, older women are more likely to have amniocentesis, further increasing costs of delaying childbearing.

Similarly, the characteristics of ART babies may be different from those naturally conceived. The most important difference is that there is a tenfold increase in multiple births following IVF compared to the overall population, and multiple births are at higher risk for adverse neonatal outcomes. Furthermore, although ART does not seem to increase

³⁸ In health economics this is often measured in QALYs, a measure of the outcome of actions (either individual or treatment interventions) in terms of their health impact.

the risk of malformations or cancer, low birth weight and prematurity are more likely.^{39,40} Looking to the future, genetic screening may become more prevalent for ART babies and thus there could be an associated long-term morbidity.

These health effects and other unintended consequences should be taken into account when assessing the impact of ART as part of a population policy mix. In the following slides we will look into one of these aspects in more detail: the potential impact on further delay of childbirth.

³⁹ See for example: Editorial (2004). *The State of ART*. Science 29 October: **306** (5697): 808; or Schieve et al. (2004). *Are Children Born After Assisted Reproductive Technology at Increased Risk for Adverse Health Outcomes?*. Obstetrics & Gynecology; **103**: 1154-1163.

⁴⁰ Public policies could focus on single embryo transfer, which effectively reduce the incidence of low birth weight and prematurity almost to that of spontaneously conceived singleton pregnancies.

A recent Guardian poll found that around 35% of the Britons may consider choosing to postpone childbearing because of the availability of ART.⁴¹ The hypothetical situation depicted in the slide above illustrates the potential effect of such postponement on the TFR, based on 2002 data for the UK (green line).

The red line illustrates a quantum effect of increased uptake of ART,⁴² assuming that the proportional effect is similar across all age-groups.⁴³ The resulting TFR in this case will be higher than in the base case. However, as suggested previously, couples may choose to postpone childbirth given the prospect of successful ART treatment. The blue line therefore assumes that a certain proportion of the population choose to postpone childbirth by a certain period.

Such postponement will have a tempo-effect on the TFR,⁴⁴ causing it to decrease temporarily. Compared to the base scenario (green line), the age-specific fertility will be lower for younger women, while it will be higher for older women. An unintended effect of postponement may be that people choose to delay their childbirth too much. When

⁴¹ The question in the survey was “Do you think that progress in fertility technology would make people like you consider delaying having children?” Source: The Guardian (2006) Britons put work and fun before babies, May 2, 2006

⁴² Quantum effects reflect the changes in TFR that would have been observed in the absence of changes in the timing of childbearing during the period in which the TFR is measured. See: Bongaarts and Feeney (1998). On the Quantum and Tempo of Fertility. *Population and Development Review*, **24** (2): 271–291.

⁴³ The differences in this example are exaggerated to illustrate the concept.

⁴⁴ Tempo effects equal the distortion in TFR that occurs due to changes in the timing of child birth. *Op cit.* Bongaarts and Feeney (1998).

older, they may encounter difficulties conceiving and end up not having the child they would have had without postponement. In the absence of a behavioural-biological model, it is assumed that the downward slope of the red line represents a boundary beyond which childbirth cannot be delayed due to sub-fertility.⁴⁵ This is shown in the slide by the conjunction of the red and blue line illustrating the limiting factor of age on childbearing. In this hypothetical case, the age-specific fertility rates beyond age 32 cannot be increased through postponement.

See Appendix A for a technical explanation of these phenomena.

⁴⁵ In reality, however, there is no discrete moment at which a couple becomes sub-fertile. Instead, the average period of unprotected intercourse until pregnancy (time-to-pregnancy) increases with age.

The previous slide explained that the impact of postponement of childbirth on the TFR depends on two variables: 1) the proportion of the population that chooses to postpone; and 2) the number of years of postponement.

The slide above illustrates the threshold values at which the combination of the two variables has a neutral effect on assisted TFR in the UK (i.e., the 0.04 quantum effect that would result if the number of ART births in the UK increased to levels similar to those in Denmark). The area above the red curve shows the cases when the tempo effects of ART cancel the quantum effects and the new fertility rate is below the fertility rate before ART was introduced. Therefore, for ART to be effective, people's choices would need to remain below the red curve – i.e. a small fraction must choose to postpone or they must not postpone for long.

It should be taken into account that this diagram assumes that all couples that choose to postpone do so with a fixed period, whereas in reality there are distributional differences due to individual choice.

Previous slides illustrated the effects of postponing without analysing the actual behaviour of couples. In Appendix A we have explained our preliminary work on a behavioural model of fertility and ART. It is exploratory and not intended to produce quantitative results. Even without input data, several observations can be made from the theoretical interactions between income, the costs of children, fecundity and fertility. One of the key aspects is that fertility and the (direct and indirect) costs of children are negatively correlated. The costs of children include the opportunity costs of lost earnings by the mother, assuming that a woman has to stop working at the time of family formation.

In the above example, we have chosen the parameters so that the model (red line) is fitted to the empirical age-specific fertility rates of Denmark (blue data points).⁴⁶ The simulated TFR matches the observed TFR in 2002.

In scenario 1, we assumed that couples are aware of the availability of ART if they encounter difficulties in conceiving children. This change has two important impacts. First, the availability of ART creates the perception that sub-fertility at a later age can be treated. The trade-off, between reducing household income due to childbirth and the disadvantage of potential sub-fertility due to further delay, turns in favour of postponement. The blue line indicates that fertility rates are lower than the base case for younger women, while they are higher for women older than 35. A second impact is a reduction in TFR. The cost of ART causes the direct cost of children to increase and, as a result, the TFR declines.

⁴⁶ The relatively high proportion of teenage pregnancies implies that the age-specific fertility rates for the UK are more difficult to simulate.

In scenario 2, we assumed that there are no costs involved with ART treatment: i.e. couples do not themselves have to pay for ART (only indirectly through taxes). The impact of this change is a proportional increase in age-specific fertility rates due to the reduced costs of children.

In sum, the theoretical interactions in this preliminary behavioural model suggest the existence of a postponement effect of ART. The extent of this effect could be influenced through tailoring an ART policy to specific age groups, i.e. women under age 35.

Concluding observations

There is potential for ART in a population policy mix

- Population ageing will have negative consequences on economics and social cohesion of Europe
- Policy options to date have included immigration, welfare reform, and family policy
- The impact of ART on fertility is likely to be small - it is comparable to other population policy measures
- There is potential for ART as part of a population policy mix
- ART may lead to further postponement of child birth, which could potentially undo its positive effect on TFR
- Further analysis is needed to quantitatively assess the intended and unintended effects of ART

In recent years, European and Asian governments have begun to acknowledge the causes, consequences and implications of low fertility and population ageing. Whilst the most direct way to mitigate the future impact of an ageing population is through the redesign of the welfare state (by, for example, raising retirement ages), if governments wish to tackle the problem at the source they will need to increase fertility rates.

Traditionally, governments have focused on financial incentives to increase the affordability of children, or labour market policies to reconcile work and family. One strategy that has not been systematically examined is related to helping sub-fertile couples to achieve their desired family size through assisted reproductive technologies. As far as we are aware, the effectiveness of ART within the population policy mix has not been evaluated. In this study, we have assessed the demographic impact of ART on fertility rates, examined whether ART in the context of population policy is economically viable, and outlined some of the consequences of using ART to influence fertility rates. Within the context of a population policy mix, these preliminary results may mean that European governments wish to review their reimbursement policies of ART. However – as outlined in Appendix B - further work is needed to develop and refine the model developed for the study and to understand some of the complex behavioural responses that are likely to occur if ART became part of a population policy mix.

Appendix A. Technical annex

The following pages provide a technical appendix to the Documented Briefing. The appendix is composed of five main sections. In the first one, the fertility model is described. The second one describes the technicalities behind the cost-benefit analysis of potential policies involving ART. The third section presents the reasoning behind the empirical tempo effect analysis. The fourth section describes the population dynamics model used to produce future projections. Finally, the last section describes the initial work on a behavioural model.

Throughout the text the terms *fecundity* (or *biological fertility*), *desired fertility* and *observed fertility* are used. In order to avoid confusion they are defined here as:

- **Fecundity (or biological fertility):** the ability to conceive without protection⁴⁷;
- **Desired fertility:** a couple's ideal number and timing of children;
- **Observed fertility (or fertility):** the combination of the above, which shows up in national fertility statistics. When the term *fertility* is used, this means observed fertility.

A1. Fertility model

This section presents the deterministic fertility model. The model quantifies the potential magnitude of the effect of ART policies upon the total fertility rate (TFR). The model neglects behavioural components, and therefore cannot account for people's willingness to undergo ART treatment. We recommend that this should be incorporated in future research.

The model

The total fertility rate is given by:⁴⁸

$$TFR = \sum_a ASFR_a \cdot \Delta a \quad \text{AI.1}$$

where a is the age band and Δa is the size of the age band. On the other hand

$$ASFR_a = \frac{b_a}{n_a} \quad \text{AI.2}$$

is the age-specific fertility rate, n_a is the number of women in age band a , and b_a is the number of births from women in age band a . Please note that, for clarity of exposition,

⁴⁷ A sub-fecund couple is unable to conceive after two full years of regular heterosexual intercourse without the use of contraception

⁴⁸ See for example: Weeks (1999), Population – An introduction to concepts and issues. Wadsworth Publishing Company.

from now on the age-specific subscript a will be omitted, and therefore all formulae apply to each age band.

In general, the age-specific fertility rate may be divided into two components: on the one hand the fertility rate of fertile women, say $ASFR_F$; on the other hand the fertility rate of sub-fertile women, say $ASFR_{SF}$:

$$ASFR = g(ASFR_F, ASFR_{SF}) \quad \text{AI.3}$$

Breaking the total fertility rate into these two components will simplify the analysis of each by allowing us to focus on the respective properties. At this stage it is assumed that the possibility of ART treatment does not affect $ASFR_F$, only $ASFR_{SF}$. This assumption may be inaccurate because, for example, fertile couples may choose to delay their first baby knowing that they could still recur to ART treatment if needed later on.⁴⁹ At this stage, however, we choose to focus on those aspects that are independent and to note down those that may need a more elaboration.

The rest of this section formally derives the form of function $g(ASFR_F, ASFR_{SF})$ from first principles. The total number of births is given by the sum of unassisted births, b_n , and assisted⁵⁰ births,⁵¹ b_{ART} :

$$b = b_n + b_{ART} \quad \text{AI.4}$$

Then, the number of women⁵² can be divided into the number of fertile, n_f , sub-fertile, n_{sf} , and sterile women (defined as those women for whom ART treatment is ineffective.) n_{nf} :

$$n = n_f + n_{sf} + n_{nf} \quad \text{AI.5}$$

It is now possible to define the age-specific fertility rates for fertile and sub-fertile women as:

$$ASFR_F = \frac{b_n}{n_f} \quad \text{and} \quad ASFR_{SF} = \frac{b_{ART}}{n_{sf}} \quad \text{AI.6}$$

and the fraction of fertile, f , and sub-fertile, sf , women:

$$f = \frac{n_f}{n} \quad \text{and} \quad sf = \frac{n_{sf}}{n} \quad \text{AI.7}$$

Furthermore, the number of assisted births can be given in terms of the number of cycles, N_C , and the success rate, σ , of each cycle:

⁴⁹ A Guardian poll found that indeed around 35% of couples may choose to postpone childbearing because of the availability of ART (Source: Britons put work and fun before babies, The Guardian, May 2, 2006).

⁵⁰ Here the term “assisted births” refers to babies born through ART treatment, while “unassisted births” refers to babies born without ART treatment.

⁵¹ In this analysis we are not considering the effects of birth orders (i.e. first, second child...). This should eventually be included in a behavioural model.

⁵² In this work we have considered female fecundity only. This neglects the effects of male or couple fecundity. Future research should address this issue.

$$b_{ART} = N_C \cdot \sigma \quad \text{AI.8}$$

Using the above set of assumptions and definitions it is possible to derive formally the actual equation for the age-specific fertility rate:

$$ASFR = f \cdot ASFR_F + sf \cdot ASFR_{SF} \quad \text{AI.9}$$

In words, Equation AI.9 says that the age-specific fertility rate is given by the age-specific fertility rate of fertile women times the proportion of fertile women, plus the age-specific fertility rate of sub-fertile women times the proportion of sub-fertile women.

Scenarios

There is a vast literature on fertility models, and data on future projections are available. As a first approximation we can consider $ASFR_F$ as a constant. By this we don't mean that it would stay constant over time, but that we could obtain a numerical value from other the literature.

By doing this we can concentrate on the effects of ART on the total fertility rate. For example we can look at the sub-fertile fraction of the population, and see how the total fertility rate would change if some of these people were to undergo ART treatment. However, note that at this stage the model does not have a behavioural component, so the results do not take into account people's willingness to undergo ART treatment.

In Equation AI.9, f , $ASFR_F$ and sf are determined empirically. On the other hand, $ASFR_{SF}$ can be varied by the use of ART. This section manipulates Equation AI.9 to produce a number of different scenarios.

Observed age-specific fertility

The observed age-specific fertility rate ($ASFR_O$) can be reproduced by estimating the above parameters and using Equation AI.9. This validates the model.

Unassisted age-specific fertility

This limit case ($ASFR_U$) is represented by the births that are not conceived through ART, which occurs when $ASFR_{SF}=0$, which leads to:

$$ASFR_U = f \cdot ASFR_F \quad \text{AI.10}$$

This corresponds to the case when no sub-fertile women have access to ART.

Equivalent age-specific fertility, $ASFR_{DK}$ and $ASFR_{UK}$

This scenario is devised to compare the fertility rates in Denmark and the UK. In this case:

$$ASFR_{SF} = ASFR_{SF}(DK), \text{ for the UK} \quad \text{AI.11}$$

$$ASFR_{SF} = ASFR_{SF}(UK), \text{ for Denmark}$$

This can be achieved in a number of ways using Equation AI.8. In the simplest theoretical case, the number of births can be varied directly, independently of the number of cycles used or their success rates. In reality, however, this can only be done by changing either

the number of cycles or their success rate. Since the success rates in the UK and Denmark are similar (see the following sections on empirical data), the proportion of ART births in the UK can be brought to the Danish level by tripling the number of cycles in the UK.

Maximum age-specific fertility, $ASFR_m$

Fertility can be increased by providing more ART treatments. The maximum limit may be seen as the case when, through ART, sub-fecund women attain the same fecundity level of fecund women: $ASFR_{SF}=ASFR_F$, which leads to:

$$ASFR_m = (f + sf)ASFR_F \quad \text{AI.12}$$

It is noteworthy that $ASFR_m=ASFR_F$ when $f+sf=1$; that is when there are no infertile women, $nf=0$. On the other hand, $ASFR_m<ASFR_F$ when $f+sf<1$; that is when there are infertile women for whom ART treatment is ineffective, $nf>0$.

Empirical data

This section presents the empirical data collected.

Age-specific fertility rates

Table 1 shows the age-specific fertility rates for the UK. These lead to a total fertility rate of $TRF=1.64$. Also shown are the age-specific fertility rates for Denmark. These lead to a total fertility rate of $TRF=1.72$.

Table 1. Observed age-specific fertility rates (ASFR) for the UK and Denmark

Age band	United Kingdom (2002)	Denmark (2002)
15-19	0.0273	0.0066
20-24	0.0682	0.0477
25-29	0.0911	0.1223
30-34	0.0902	0.1159
35-39	0.0428	0.0449
40-44	0.0083	0.0072
45-49	0.0001	0.0001

Source: Eurostat (2002)

Proportion of sub-fertile couples

The first point to note about the data availabilities for the proportion of sub-fertile (women who can benefit from ART treatment) women is that it is difficult to obtain reliable accepted values. The same applies to the number of infertile women (for whom ART treatment is ineffective).

This is a problem that is intrinsic to the data for two reasons: definition and measurement. As far as the definition is concerned, the problem is that different sources define sub-fecundity differently. For example, the International Council on Infertility Dissemination considers a couple to be sub-fecund if:⁵³

⁵³ International Council on Infertility Dissemination (INCIID) (<http://www.inciid.org/faq/general1.html>).

- They have not conceived after 12 months of unprotected intercourse, or after 6 months if the woman is over 35 years of age;
- There is incapability to carry a pregnancy to term.

Other sources consider 24 months of unprotected intercourse as the threshold.

The other issue regards measurement. Figure 1 shows values for the proportion of sub-fertile women as a function of age.^{54,55} It is clear that there is a non-insignificant variation. Moreover, studies show that these values vary significantly if the average number of unprotected intercourses per week is changed.⁵⁶

A further issue is that relevant data is rare for ages beyond 40. This should not be a major issue because the ASFRs are low at those ages.

In this study it was decided to use an average of the values shown in Figure 1 for input into the models. Future studies, however, should address this issue in more detail; the lack of information on the matter in the literature points to the fact that the issue may deserve a dedicated study of its own.

Table 2 shows the values for the percentage of sub-fertile women used in the model.

Figure 1. Different measures of the fraction of sub-fertile women by different authors.

⁵⁴ Bongaarts (1982). Infertility after age 30: a false alarm. *Family Planning Perspectives*, **14**: 75-8.

⁵⁵ Van Balen, Verdurmen and Ketting (1997). Age, the desire to have a child and cumulative pregnancy rate. *Human Reproduction*, **12** (3): 632-627.

⁵⁶ Dunson *et al* (2004) Increased fertility with age in men and women. *Obstetrics and Gynecology*, **103**: 51-56.

Table 2: Values for the percentage of sub-fertile women used in the model

Age Band	Percentage of women who are sub-fecund
15-19	5%
20-24	8%
25-29	10%
30-34	12%
35-39	20%
40-44	35%
45-49	70%

Number of women in reproductive age

Table 3 shows the total number of women during the fertile years by age band for both the UK and Denmark.

Table 3. Total number of women per age band during the reproductive years.

Age band	United Kingdom	Denmark
15-19	1,814,520	138,193
20-24	1,804,232	156,508
25-29	1,923,408	187,100
30-34	2,280,970	191,660
35-39	2,367,170	208,431
40-44	2,136,014	186,029
45-49	1,904,875	182,285

Source: Eurostat (2002)

Number of cycles by age band

Equation AI.8 expresses the number of ART births in terms of the success rate, σ , and the number of cycles N_C . This section focuses on the latter, while the next one will delve into the former.

Data on the total number of cycles are available for both the UK⁵⁷, $N_{Ctot}=37,083$, and Denmark, $N_{Ctot}=11321$. We do not have data for the number of cycles by age band. However, we know how the total number of cycles is distributed among age bands. Table 4 shows the distribution of the number of ART cycles by age band, $f_{ART}(a)$. Note that only the fractions by both IVF (f_{IVF}) and ICSI (f_{ICSI}) are available. From these, it is possible to obtain $f_{ART}(a)$ through the following weighted average:

$$f_{ART}(a) = \frac{n_{IVF} \cdot f_{IVF}(a) + n_{ICSI} \cdot f_{ICSI}(a)}{n_{IVF} + n_{ICSI}} \quad \text{AI.13}$$

⁵⁷ Op cit. Nyboe Andersen *et al.* (2006).

where n_{IVF} and n_{ICSI} are the number of IVF and ICSI treatment cycles, respectively. For the UK the values are: $n_{IVF}=16152$ and $n_{ICSI}=11521$; while for Denmark they are: $n_{IVF}=6067$ and $n_{ICSI}=3563$.⁵⁸

From the above, we now have an estimate of the number of cycles per age band:

$$N_C(a) = N_{C_{tot}} \cdot f_{ART}(a) \quad \text{AI.14}$$

Table 4. Fraction of women treated with IVF, ICSI and the calculated value of ART.

Age band	United Kingdom			Denmark		
	f_{IVF}	f_{ICSI}	Weighted average f_{ART}	f_{IVF}	f_{ICSI}	Weighted average f_{ART}
15-19	0	0	0	0	0	0
20-24	0	0	0	0	0	0
25-29	0.119	0.151	0.132	0.207	0.275	0.232
30-34	0.348	0.375	0.359	0.357	0.393	0.370
35-39	0.389	0.363	0.378	0.346	0.265	0.316
40-44	0.135	0.105	0.123	0.081	0.059	0.073
45-49	0.009	0.007	0.008	0.009	0.007	0.008

Source: Nyboe Andersen et al. (2006)

Success rates

The second term required by Equation AI.8 is the success rate, σ . We have the aggregate values (i.e. not disaggregated by age) for the UK⁵⁹, $\sigma_A=0.255$, and for Denmark, $\sigma_A=0.237$. Table 5 shows the observed success rates, $\sigma_0(a)$, as a function of age band. Although these are the most up to date values available, they refer to the period 1995-1999⁶⁰ and are therefore slightly out of date.

Table 5: Observed and adjusted success rates.

Age band	Observed success rates, σ_0	Adjusted success rates, σ
15-19	0.21	0.33
20-24	0.21	0.33
25-29	0.21	0.33
30-34	0.20	0.31
35-39	0.15	0.24
40-44	0.05	0.08
45-49	0.01	0.02

Due to technological advances, these values have increased in recent years. It was decided to adjust these values using the following equation:

⁵⁸ Op cit. Nyboe Andersen *et al.* (2006).

⁵⁹ Ibid

⁶⁰ Op cit. National collaborating centre for women's and children's health. (2003)

$$\sigma(a) = \phi \sigma_0(a) \quad \text{AI.15}$$

where the parameter ϕ quantifies the technological advances and needs to be estimated empirically. In other words, the observed distribution of the success rates with age is maintained, but their magnitude is increased. The value of ϕ is obtained by constraining it to satisfy:

$$b_{ART,tot} = \sum_a N_C(a) \cdot \phi \cdot \sigma_0(a) \quad \text{AI.16}$$

In other words, the success rates were increased as to reproduce the observed number of total births, $b_{ART,tot}$. The estimated value for the UK is: $\phi=1.57$.

As a confirmation of the validity of this approach, the weighted average of the success rate for the UK

$$\sigma_A = \frac{\sum_a \sigma(a) \cdot N_C(a)}{\sum_a N_C(a)} = 0.255 \quad \text{AI.16}$$

returns the observed value, as expected.

Number of ART births

It is now possible to return to Equation AI.8, rewritten here for ease of reference:

$$b_{ART}(a) = N_C(a) \cdot \sigma(a)$$

This equation relates the number of ART cycles to the number of births. Then, through Equation AI.9, this can be used to explore the effect on age-specific fertility rates and to the total fertility rate. For example, by varying the total number of cycles (see Equation AI.14) the total number of births is affected.

A2. Cost-benefit analysis: calculation details

In the Documented Briefing the results from the fertility model were used to produce a cost-benefit analysis of potential ART policies. This section describes in detail the calculations behind the cost-benefit analysis.

The total cost of ART, C_T , is given by:

$$C_T = C \cdot \sum_a T_C(a) \quad \text{AII.1}$$

where $C=\text{£}2,771^{61}$ is the cost of one IVF cycle and $T_C(a)$ is the total number of cycles used, which varies across the age bands a , and is given by:

$$T_C(a) = \Delta b(a) \cdot n_C(a) \quad \text{AII.2}$$

⁶¹ *Op cit.* National collaborating centre for women's and children's health. (2003) p. 270.

In Equation AII.2, $n_C(a)$ is the average number of cycles required to produce a baby. This increases with age. $\Delta b(a)$ is the extra number of babies born through ART⁶² so that the current UK TFR matches the TFR in Denmark; this variable changes for different age groups.

The number of cycles required to produce a baby was calculated from:

$$n_C(a) = \frac{1}{\sigma(a)} \quad \text{AII.3}$$

where $\sigma(a)$ is the success rate of the ART treatment by age. The values used are:⁶³

- 0.21 for women below 30 years of age;
- 0.20 for women between 30 and 34;
- 0.15 for women between 35 and 39;
- 0.05 for women between 40 and 44; and
- 0.01 for women between 45 and 49.

Scenarios

The scenarios presented here apply to the United Kingdom. Table 6 summarises the results.

In Scenario I, the UK TFR is allowed to increase up to the Danish level. In this case ART is provided to women of all ages. TFR increases by 0.0423 at a cost of £427M. It is important to note that as the mother's age increases, the cost of an ART birth increases due to the lower success ratio for older women. In particular, after the age of 40 the increase is considerable. The model shows that the cost per birth is £55K and £277K for women aged 40-44 and 45-49, respectively.

Table 6. Cost-benefit scenarios.

Scenario	ART provided to	Total Cost ⁶⁴	TFR increase
I	All women	£429M	0.0423
II	Women aged <45	£387M	0.0419
III	Women aged <40	£259M	0.0364

For this reason two further scenarios were developed. Scenario II excludes women aged 44 or above. In this case, the total cost goes down to £385 whereas the increase in TFR goes down to 0.0419. Finally, in Scenario III ART is provided only to women aged below 40. In this case the increase in TFR is 0.0366, while the total costs are £259M.

⁶² The values for $\Delta b(a)$ were obtained from our first-order empirical model.

⁶³ *Op cit.* National collaborating centre for women's and children's health. (2003) p.157.

⁶⁴ Note that the cost in 2006 should be lower. This is because these calculations involve costs from 2003 and ART success rates from the period 1995-1999.

Comparison with other fertility policies: child benefits

The Documented Briefing compared the costs and benefits of ART policy with those of child benefits. This section describes the reasoning behind the latter.

An often-cited study is that of Gauthier and Hatzius,⁶⁵ who include a relative benefit measure in their regression analysis – the monthly amount received by a two-child family divided by the average monthly men’s wage in manufacturing in each country. The control variables included are the logarithm of men’s wages, the logarithm of women’s wages, the unemployment rate, the first-order difference of the unemployment rate, duration of maternity leave in weeks, and benefits received during maternity leave.

Analysis is conducted using data for 22 OECD countries covering the period 1970-90. They calculate that a 25% increase in benefits would increase the total fertility rate by 0.07 children per woman in the long run.

Costing this policy change is not straightforward due to the lack of a dataset comparable to the one used by the authors. We derive our central cost estimate by taking the mean value of family allowances as a percentage of the average men’s wage in manufacturing in 1990, as given in the paper, of 5.2%. If this rate prevailed in the UK in 2005, the value of child benefit to a two-child family would be £24 per week - 85% of its true level. We therefore adjust child benefit expenditure to 85% of its true level and then derive the cost of a 25% increase, at £2bn.

Indexing (by prices) actual child benefit amounts from the values given in the paper gives an estimate of the cost of the policy change of between £1.5 and £2bn. A 25% increase in child benefit from its current level would cost between £2bn and £2.5bn. Given this range of estimates, we give our headline cost estimate as between £1.5bn and £2.5bn.

A3. Tempo effect – technical details

This section presents a non-behavioural study of the “tempo” effects of ART. One unintended effect of ART may be to delay childbearing. The poll, mentioned earlier,⁶⁶ found that 35% of men and women in the UK would consider delaying childbirth due to the availability of fertility treatment.

Model

This section introduces a simple model to explore this issue. The question is: how would the age-specific fertility rates (*ASFR*) change if people relied on ART for prolonged fecundity? Mathematically this means that we are looking for a new age-specific fertility rate that includes the tempo effects, $ASFR_T$.

ART offers people the choice:

1. Whether to postpone their childbirth;

⁶⁵ Gauthier and Hatzius (1997). Family Benefits and Fertility: An Econometric Analysis. *Population Studies*, 51 (3): 295-306.

⁶⁶ *Op cit.* Guardian (2006).

2. How long to postpone their childbirths for.

Point 1 may be expressed mathematically with a function describing the fraction of people who would postpone childbirth:

$$fp(a) = f(a) \quad \text{AIII.1}$$

In general, this would be a function of age as younger people may rely on their natural fecundity, while older people reaching the end of their fertile lives may be more sensitive to technological alternatives.

Similarly, point 2 may be expressed by a function that describes the number of years people may be willing to delay having babies:

$$yp(a) = g(a) \quad \text{AIII.2}$$

Again, this may be a function of age.

For simplicity, here we assume that both $fp(a)$ and $yp(a)$ are constant with age, i.e. $fp(a)=fp_0$, $yp(a)=yp_0$.

The new age-specific fertility rate $ASFR_T(a)$ would modify the fertility rate unaffected by time $ASFR_{DK}(a)$. (As a case study, $ASFR_{DK}(a)$ represents the UK age-specific fertility rate that has been brought to the Danish level, see Figure 2). Mathematically this may be expressed as:

$$ASFR_T(a) = ASFR_{DK}(a) - fp_0 \cdot ASFR_{DK}(a) + fp_0 \cdot ASFR_{DK}(a - yp_0) \quad \text{AIII.3}$$

In words, this equation is saying that the new fertility rate would be reduced by the fraction of people choosing to delay childbirth. On the other hand, this would be increased by those people who decided to postpone childbirth at an earlier stage.

Unintended effects

Equation AIII.3 assumes that the total number of babies remains the same; the only change is the timing of their births. However, an unintended effect of postponement may be that people choose to delay their childbirth too much, and end up not having the child they would otherwise have had. This results in a reduction of the total fertility rate.

In the absence of a behavioural-biological model, here it is assumed that the downward slope at the right of the diagram in Figure 2 represents a boundary beyond which childbirth cannot be delayed. In other words, the age-specific fertility rates beyond age 32 cannot be increased through postponement.

Mathematically this means that Equation AIII.3 is valid if $ASFR_T \leq ASFR_{DK}$. On the other hand, if $ASFR_T > ASFR_{DK}$ then $ASFR_T(a) = ASFR_{DK}(a)$.

Figure 2. Empirical data for the UK (Source: Eurostat 2002) and model results.

Figure 2 shows the observed age-specific fertility rates for the UK, $ASFR_{Obs}$. The diagram also shows $ASFR_{DK}$ and the new fertility that includes both quantum and tempo effects, $ASFR_T$. For the three scenarios it is possible to obtain the respective total fertility rates: TFR_{Obs} , TFR_{DK} , TFR_T .

For different fractions of people choosing to postpone different number of years, there will be cases when $TFR_{Obs} < TFR_T$ but also unwanted cases when $TFR_{Obs} > TFR_T$. In words, there may be circumstances when the tempo effects cancel the quantum effects of ART policy.

Figure 3 shows the various possible scenarios, for different value of fp_0 and yp_0 . The area above the red curve includes the cases when the tempo effects of ART cancel the quantum effects and the new fertility rate is below the fertility rate before ART was introduced. Therefore, for ART to be effective, people's choices need to remain below the line.

Figure 3. Combined quantum and tempo effects of ART on the total fertility rate

A4. Population dynamics module

This section presents a population dynamics model. The main goal of the model is to translate fertility rates into time dependent population dynamics. The main inputs to the population model are the results from the fertility model. Therefore, this model allows us to project into the future the effect that different scenarios of fertility may have on the population age structure. These outputs, in turn, can be used to explore the socio-economic impacts of different ART-affected fertility rates.

A number of considerations have been made while developing the model. The set of equations has been devised to be simple to manipulate. The data requirements have been reduced to a minimum. However, if more accuracy is required, the model can be readily adapted and extended. The following subsections briefly present the model components

Population growth rate

Equation AIV.1 is a well-established differential equation that describes the dynamics of the aggregate population growth. It allows us to know how the total population, N , will evolve depending on the number of births and deaths, as well as migration effects.

$$\frac{dN}{dt} = (b - d)N + m \quad \text{AIV.1}$$

Here b is the birth rate, and is directly dependent on the age-specific fertility rates, and d is the death rate. Finally the migration term, m , is the balance between immigration and emigration, and can be set to zero as a first approximation.

Population age structure

The population age structure is given by $n(a)$, which describes the number of people at each age a . Generally, the initial population distribution is determined empirically⁶⁷ while the model predicts endogenously its evolution over time. Assuming no net immigration, equation AIV.2 relates the population distribution to the total population. In words, the total population is the sum of all people across all ages.

$$N = \int_0^{\infty} n(a) da \quad \text{AIV.2}$$

The population age structure will evolve with time according to:

$$n(a)_t = n(a-1)_{t-1} P_L(a) \quad \text{AIV.3}$$

In words, Equation AIV.3 is saying that the number of people of age a is equal to the number of people of age $a-1$ in the previous year who are still alive. The term $P_L(a)$ describes the probability of a person of age a of being alive, and needs to be determined empirically.

Number of births

The fertility rates drive the dynamics of the model by determining the number of births at any given time, $b(t)$:

$$b(t) = \sum_a ASFR_a \cdot n_{wa}(t) \quad \text{AIV.4}$$

Where $ASFR_a$ is the age-specific fertility rate of age band a , and $n_{wa}(t)$ is the number of women in age band a .

The number of births varies each year because the number of women changes. However, here the age-specific fertility rates are assumed to be constant over time.

Probability of still being alive

Figure 4 and Figure 5 show the probability of still being alive as a function of age, $P_L(a)$, for women and men in the UK, respectively. $P_L(a)$ is related to the probability of dying by $P_L = 1 - P_D$. The plots show both data⁶⁸ (for years 1982/4, 1992/4, 2002/4) and a theoretical function that fits the 2002/4 data. The data applies to the United Kingdom.

$$P_L(a) = \left(1 - \frac{1}{1 + e^{-\beta(a-\alpha)}}\right) \left(1 - \left[\frac{a}{\delta}\right]^\gamma\right) \quad \text{AIV.4}$$

This function is specified by three parameters that are obtained empirically to fit the data: α , β , γ and σ . For women in 2002/4, the parameters take the following values: $\alpha=90$, $\beta=0.15$, $\gamma=6$, $\delta=100$. For men they are: $\alpha=87$, $\beta=0.15$, $\gamma=4.5$, $\delta=100$. As the diagram

⁶⁷ The scenarios presented for both the UK and Denmark use the 2002 population structure as provided by the Eurostat (2002).

⁶⁸ Source: The Government's Actuary Department. (2006) Available at: http://www.gad.gov.uk/Life_Tables/Interim_life_tables.htm. Accessed on: April 22, 2006.

shows, the curve evolves over time. For simplicity reasons however, the model assumes that the curve remains constant at the value of 2002/4. Note that, although in this project we are studying the fertility of both Denmark and the UK, we are focusing on population projections for the UK only. For this reason we are not estimating the parameter values for Denmark.

Figure 4. Probability of living for women in the UK. Data (1982-4, 1992-4, 2002-4) and model for 2002-4.

Figure 5. Probability of living for men in the UK. Data (1982-4, 1992-4, 2002-4) and model for 2002-04.

Dependency ratios

Once the dynamics of the population age structure have been obtained, it is possible to derive a number of indicators that allow us to get an insight into the evolution of the socio-economic circumstances. In this section three formulae for the dependency ratios are obtained:

- Full dependency ratio;
- Old age dependency ratio; and
- Young age dependency ratio.

These are presented in the following sections.

Full dependency ratio

Here the full dependency ratio is defined as the number of people in non-working age (between 0 and 15 and 65 or older) divided by the number of people of working age (16-64). The dependency ratio can be written as:

$$DR = \frac{\int_0^{15} n(a) da + \int_{65}^{\delta} n(a) da}{\int_{16}^{64} n(a) da} \quad \text{AIV.5}$$

Note that the upper limit for old age is δ years, as estimated through Equation AIV.4.

Old- and young-age dependency ratio

The old age dependency ratio (ODR), on the other hand, describes the ratio of old-age people to working age people. Finally, the young age dependency ratio (YDR) describes the ratio of young people to working age people.

$$ODR = \frac{\int_{65}^{\delta} n(a) da}{\int_{16}^{64} n(a) da} \quad \text{AIV.6}$$

$$YDR = \frac{\int_0^{15} n(a) da}{\int_{16}^{64} n(a) da} \quad \text{AIV.7}$$

A5. Behavioural model

This section presents our preliminary work on a behavioural model of fertility. **The work to be presented is exploratory in nature and is not meant to produce quantitative results. The goal is to show that a behavioural model of fertility can be developed from first principles based on rational theory.** The modelling technique is based on the groundbreaking work of Gary Becker.^{69,70} At this stage the model produces general

⁶⁹ Becker (1981) *A Treatise on the Family*. Cambridge, MA: Harvard University Press.

⁷⁰ Ermisch (2003) *An Economic Analysis of the Family*, Princeton, Princeton University Press.

theoretical predictions, but these are not yet supported by data and therefore cannot be used in specific case studies. One of the main advantages of this model is that it can describe explicitly the complex relationships between socio-economic as well as biological variables and fertility.

The following pages are structured as follows: the first section presents the results, i.e. an explicit equation for ASFR. The second section explains the general framework behind the model. The third section derives from, first principles, an equation for the desired number of children, while the fourth obtains an expression for the timing of childbearing. Finally, the fifth section puts all the above elements together and derives the explicit formula for the age-specific fertility rates, *ASFR*.

Preliminary behavioural model of fertility - main results

This section summarises the main results. The models are derived in detail in the following sections.

It is possible to model mathematically the age-specific fertility rates, and therefore the total fertility rates. This is done by describing people as rational actors whose actions are subject to constraints, and who are able to make choices in order to maximise their own benefit based on their set of preferences.

The following equations are only a simple model to show the type of results that can be obtained using this method: this is only the first step and more complex formulations are possible. In this case, women are allowed to work and earn until the age when they choose to have children. Basically they can choose to have children early and loose potential income, or earn more but at the cost of reducing the chances of having a child. People have an inaccurate knowledge of their decreasing fecundity, in the sense that they know that after a certain age it will start decreasing steeply, but they do not exactly know when this would happen. Also, people have a relative preference of income over children, or vice versa.

The following formula describes the age-specific fertility rates obtained from the model:

$$ASFR := \frac{1}{2} \frac{A w T b (1 - e^{(\alpha (T b - \beta (1 + g)))}) \sqrt{2} e^{\left(- \frac{\left(\ln \left(\frac{T b \alpha A + A + 1}{1 + A} \right) + T b \alpha \right)^2}{\alpha (1 + g)} - \beta \right)} \sigma^2}{(p_n + p_{ART} - \rho) (1 + A) \sigma \sqrt{\pi}} \quad AV.1$$

The ASFRs depend on people's preference of children over income, A , on the yearly wages, w , on the cost of children, p_n , as well as on the cost of an ART birth, p_{ART} . The reimbursement of ART costs, ρ , also affect people's decisions, as does their biological fecundity, described through parameters α and β . The biological fertility (fecundity) can be modified by ART through the parameter g , in this case by delaying the onset of sub-fecundity. The meaning of the parameters and variables is described in more detail in the following sections.

From the age-specific fertility rates is possible to obtain the total fertility rate:

$$TFR := \int \frac{1}{2} \frac{A w Tb (1 - e^{(\alpha (Tb - \beta (1+g)))}) \sqrt{2} e^{\left(-\frac{\left(\ln\left(\frac{Tb \alpha A + A + 1}{1+A} \right) + Tb \alpha \right)^2}{\alpha^2 (1+g)^2} - \beta \right)}}{(p_n + p_{ART} - \rho) (1+A) \sigma \sqrt{\pi}} dTb \quad AV.2$$

The model can also predict the number of desired children, independently of the timing:

$$n := \frac{A w Tb}{(p_n + p_{ART} - \rho) (1+A)} \quad AV.3$$

Similarly, the model can explicitly predict the timing of birth using a *LambertW* function⁷¹:

$$Tb = \frac{\text{LambertW}\left(\frac{(1+A) e^{\left(\frac{A+1+\alpha B A (1+g)}{A}\right)}}{A}\right) A - A - 1}{\alpha A} \quad AV.4$$

All the above results depend heavily on the fecundity:

$$f_{Bio} := 1 - e^{(\alpha (Tb - \beta (1+g)))} \quad AV.5$$

Using the following parameter values is it possible to reproduce the age-specific fertility rates of Denmark, as shown on the Documented Briefing:

$$A := 10 \quad \alpha := 0.075 \quad \beta := 44 \quad \sigma := 9.5 \quad \pi := 3.14 \quad g := 0 \quad w := 0.97 \quad p_n := 5 \\ p_{ART} := 0 \quad \rho := 0$$

Figure 6 shows the obtained ASFR.

⁷¹ The Lambert function, also called the omega function, is the inverse function of $f(W) = W e^W$. This function allows us to obtain an explicit formula for the timing of births.

Figure 6. Fit of the behavioural model to empirical data from Denmark (2002).

Preliminary observations

This section presents some preliminary conclusions based on the model.⁷² Please keep in mind that this is an initial version of the model and that some assumptions may be inaccurate. At this stage, the purpose of the model is to demonstrate the viability of this method rather than to produce accurate predictions.

- 1) People generally choose to work until their fecundity starts declining sharply. Before then, the loss in earnings would be greater than the loss in fecundity.
- 2) However, it is important to note that the desired fertility is independent of wages and the costs of children. In this model people with higher incomes behave similarly to people with lower earnings. This is because people try to maximise their total earnings in the same way. Empirical data, on the other hand shows that teenage pregnancies, for example, are more likely in low-income families. However, this may be due to educational reasons rather than to earnings.
- 3) People with preferences towards children choose to have them earlier (a higher value of parameter A), to avoid the risk of not being able to have one. On the other hand, people with predilection of earnings would choose to postpone childbirth at the expense of lower fecundity.
- 4) The tendency to postpone childbirth allows the biological fertility (fecundity) to push the observed fertility below the behavioural (desired) fertility.

The following sections show the formal derivations of the models.

⁷² Although the observations here are specific to women or couples in general, the equations used for this preliminary model do not distinguish between men, women, couples or households.

General model structure: desired fertility and fecundity

This section presents the general structure of the model. It is assumed that the observed fertility is made up of two components: fecundity and desired fertility.

Empirical data suggests that desired fertility may be initially described by a Gaussian distribution:⁷³

$$f_Beh := \frac{1}{2} \frac{\sqrt{2}}{\sigma \sqrt{\pi}} e^{\left(-\frac{(a-\mu)^2}{\sigma^2}\right)} \quad \text{AV.6}$$

This is assumed in this section with the purpose of illustrating the structure of the model, in particular the interaction between fecundity and the desired fertility. The goal of the following pages is to actually derive the behavioural equation from first principles.

The data⁷⁴ also suggests that the fecundity may be described by:

$$f_Bio := 1 - e^{(\alpha(a-\beta))} \quad \text{AV.7}$$

It is important to note that fecundity can be affected by ART; for example it can increase it. In the following sections it will be shown that this, in turn, affects people's behaviour, and therefore the desired fertility.

Here the observed fertility is assumed to be the product of the biological and behavioural fertilities, $f_Obs = f_Beh f_Bio$:

$$f_Obs := \frac{1}{2} \frac{(1 - e^{(\alpha(a-\beta))}) \sqrt{2}}{\sigma \sqrt{\pi}} e^{\left(-\frac{(a-\mu)^2}{\sigma^2}\right)} \quad \text{AV.8}$$

Figure 7 shows how fecundity as a function of age, for the following parameter values $\alpha=0.075$, $\beta=44$:

⁷³ Eurostat (2002)

⁷⁴ Carcio (1998) Management of the Infertile Woman. Lippincott Williams & Wilkins, pp. 328; Rosenthal (2001) The Fertility Sourcebook. McGraw-Hill.

Figure 7. Biological fertility as a function of age. ($\alpha=0.075$, $\beta=44$)

It may be noted that empirically obtained proportion of fecund women do not go below zero, and show tail at around age 50. It is possible to model this detail, however it was found that the current model produces the same results and simplifies the model considerably.

Figure 8 and Figure 9 show how the desired fertility is reduced by the fecundity to produce the observed fertility. In the first scenario (Figure 8) assume that people choose to have babies relatively early. This may be modelled by $\mu=25$, which is the mean of the assumed Gaussian distribution.

Figure 8. Scenario in which people choose to plan childbirth relatively early.

In this case the desired fertility and the observed fertility almost overlap. Now assume that people choose to have babies much later, say $\mu=40$ (see: Figure 9).

Figure 9. People choose to plan childbirth relatively late

In this case the observed fertility is much lower than the desired fertility. This is because the fecundity is lower at later ages, which reduces the chances of having babies.

It is important to note that the above are theoretical curves. Although they do not include numerical values, they provide insight into the general properties of this process, independently of the characteristics of the country under study.

As far as the biological fertility is concerned, the function can be specified by fitting empirical data. On the other hand, a behavioural model can be developed to derive a general behavioural function from basic assumptions. This general function can then be specified to any given country by fitting it to empirical data.

The number of desired children

This section deals with the choice of the desired number of children. In this simple initial model people face a choice of how much of their income I to allocate to the cost of having children and how much to other expenses Z . Note that in this case the income, expenses and cost of children are assumed to be totals over the parent's entire lifetime.

To start, assume that people's preferences are described by the following utility function:

$$U := A \ln(n) + \ln(Z) \quad \text{AV.9}$$

The constant A quantifies the relative preference of children over lifetime income: for $A > 1$ people have a preference for children over income, and vice versa.

The budget constraint is given by the income:

$$\text{Income} := I \quad \text{AV.10}$$

and the costs:

$$\text{Costs} := (p_n + p_{ART} - \rho) n + Z \quad \text{AV.11}$$

where p_n is the lifetime cost of a natural child, p_{ART} the additional cost of a baby born through ART and ρ is the amount reimbursed by the state. This allows us to include the effects of the costs of ART as well as the effects of a reimbursement policy from the state.

The Lagrangian is given by:

$$L := A \ln(n) + \ln(Z) + \lambda (I - (p_n + p_{ART} - \rho) n - Z) \quad \text{AV.12}$$

The first-order conditions become:

$$Eq1 := \frac{A}{n} + \lambda (-p_n - p_{ART} + \rho) = 0 \quad AV.13$$

$$Eq2 := \frac{1}{Z} - \lambda = 0 \quad AV.14$$

$$Eq3 := I - (p_n + p_{ART} - \rho) n - Z = 0 \quad AV.15$$

Which lead to the following set of solutions:

$$\left[\left[n = \frac{A I}{p_n + p_{ART} - \rho + A p_n + A p_{ART} - A \rho}, Z = \frac{I}{1 + A}, \lambda = -I(1 + A) \right] \right] \quad AV.16$$

The timing of childbirth

This section describes the choice of the timing of childbirth. It is assumed that people have a desired number of children as described in the previous section. For simplicity, it is also assumed that people can have all their children at the same time. More complex models should allow for the possibility of choosing different times for births of different birth order. It is also assumed that people can work, and earn, until the age when they have their child, at which point stop working forever. In the model people also face declining fecundity, defined as the percentage chance of having a baby.

As a starting point, people's preferences may be described by the following utility function:

$$U1 := A \ln(n_{eff}) + \ln(Income) \quad AV.17$$

Where n_{eff} is the actual number of children, and is related to the number of desired children by:

$$n_{eff} := f_{Bio} n \quad AV.18$$

where f_{Bio} represents the decline in fecundity with age and may be described by the biological fertility:

$$f_{Bio} := 1 - e^{(\alpha (a - \beta (1 + g)))} \quad AV.19$$

Please note that initially a logistic function was assumed. However, it was found that the above function provides a better fit to the observed data. The function is only valid until age 48, which is taken as the upper boundary of female age at first childbirth. The empirical numbers of birth by mothers aged 48 and above are small enough to justify this assumption.

It is important to note that the parameters α and β are determined empirically from the natural fecundity. On the other hand, the constant g represents a measure of the effect that ART may have on the fecundity curve. In this simple case g shifts the fecundity decline by a number of years. However, it is possible to describe more accurately the effect that different ARTs, such as IVF or ICSI, may have on the level of fecundity, for example an increase of fecundity.

On the other hand, n is the desired number of children and is given by (see previous sections for full derivation):

$$n := \frac{A w a}{(p_n + p_{ART} - \rho)(1 + A)} \quad \text{AV.20}$$

A number of studies show that nowadays many people choose to postpone childbearing in order to increase their income (e.g. the recent poll concluded that “Britons put work and fun before babies”).⁷⁵

To take this into account, here, we define the total lifetime earnings as the average wage w times the number of working years, a .

$$\text{Income} := w a \quad \text{AV.21}$$

If the above information is included into the utility function, people's preferences are then described by:

$$UI := A \ln \left(\frac{(1 - e^{(\alpha(a - \beta(1+g)))}) A w a}{(p_n + p_{ART} - \rho)(1 + A)} \right) + \ln(w a) \quad \text{AV.22}$$

where the first term describes the effective number of children and the second term describes the income.

In accordance to rational theory, people are assumed to make rational decisions, and choose the option with highest utility for them. Using this decision mechanism, it is possible to derive an expression for the age at which people choose to stop working and to have a baby.

Now maximise the utility by changing the age a to obtain the first-order condition:

$$\begin{aligned} Eq4 := & \left(-\frac{\alpha e^{(\alpha(a - \beta(1+g)))} A w a}{(p_n + p_{ART} - \rho)(1 + A)} + \frac{(1 - e^{(\alpha(a - \beta(1+g)))}) A w}{(p_n + p_{ART} - \rho)(1 + A)} \right) \quad \text{AV.23} \\ & (p_n + p_{ART} - \rho)(1 + A) \Big/ ((1 - e^{(\alpha(a - \beta(1+g)))}) w a) + \frac{1}{a} = 0 \end{aligned}$$

Solving the above equation, the chosen time of birth Tb (the age at which to have the babies) becomes:

$$Tb := \frac{-A + \text{LambertW} \left(\frac{(1 + A) e^{\left(\frac{A + 1 + \alpha \beta A + \alpha \beta g A}{A} \right)}}{A} \right) A - 1}{\alpha A} \quad \text{AV.24}$$

This is an interesting result because it shows that people's choice is independent of their wages (please keep in mind that this is a simple formulation, and that a more complex

⁷⁵ Op cit. The Guardian, Tuesday May 2, 2006)

model may introduce income into the above equation). On the other hand, the chosen age for having a baby depends on two factors:

- People's preference (or non-preference) of babies over income; and
- Fecundity.⁷⁶

Let's explore these two results more in depth.

People's preference (or non-preference) of babies over income

The preference of babies over income is quantified by the parameter A . To obtain numerical results it is necessary to include numerical values for the parameters. Recall the values for the biological fertility:

$$\alpha := 0.075 \quad \beta := 44$$

In this case assume that there are no tempo-effect induced by the availability of ART, thus:

$$g := 0$$

It is now possible to predict the age at which people choose to have babies as a function of A , as illustrated in Figure 10. The diagram shows how the chosen age for having babies decreases as the desire for having them, A , increases. This is because people who prefer babies to income choose to stop working earlier in order to increase the chances of success. On the other hand, people who prefer earnings would delay the age at which they try to have babies and simply accept the fact that the chances of success are lower.

Figure 10. The correlation between the chosen age for having children and the desire for having them

It is interesting to note that the age for having babies is controlled strongly by the fecundity. This can be seen from the small slope of the curve for large values of A . This means that a much larger preference for babies does not lead to a much earlier age for having them. People, who want to have babies more than money choose to delay having them until their fecundity starts declining sharply, see biological fertility curve. This would allow them to maximise their chances of having babies while maximising their income.

⁷⁶ This point is particularly important for our study, because ART affects directly the biological fertility, and therefore people's choices

What would happen if the fecundity curve changed? This question is addressed in the next section.

The effect of fecundity

From the above arguments, it is clear that the fecundity plays a central role in people's decisions. The parameter g in the fecundity is particularly interesting because through ART it effectively can control when the fecundity begins to decline sharply. For $g=0$, there is no ART, while $g>0$ implies that ART is being used to delay the decline in fecundity. A larger g means that women are effectively more fertile for longer. For example, $g=0.1$ delays the decline of fecundity by 10%. For this reason it is important to understand the behaviour of people as g is changed. Keeping the same parameter values as above, assume $A=10$. The following diagram shows how the timing of childbearing Tb increases as g increases.

Figure 11 illustrates the age at which people choose to have their babies as a function of g . The diagram clearly indicates that as the decline of fecundity is delayed, possibly through ART, people choose to delay the time at which to have their baby.

Figure 11. Age at which people choose for children as a function of biological fertility

Age-specific fertility rates

The previous sections derived an expression for the desired number of children, n , and one for the timing of childbirth, Tb . Here, these results will be combined to obtain an expression for the age-specific fertility rates, $ASFR$.

Until this point the model assumed that people have a perfect knowledge of their fecundity. (Note that here the fecundity is assumed to be the same for all people). Mathematically, this means that α and β have exact values. In reality this would not be the case. A better description would be to assume that people have a "perceived biological fertility". This means that they do not know exactly what their fecundity is, but they have an "informed guess". In other words, different people have different "perceived fertilities" which would depend on the source of information they have been exposed to. However, it is reasonable to assume that the perceived fecundities would be distributed around a common average: for example, some people may think that their fecundity begins to decline sharply at 28, while others may think this occurs at 32.

It may therefore be possible to describe the perceived fecundity through a probability distribution. In this case assume that α (which describes the steepness of the decline of biological fertility over age) and β (which describes when the fecundity declines, a higher β meaning that the fecundity declines later) are constants. In this context it is possible to describe the "perceived fecundity" with a Gaussian distribution $P_f(B)$ around a mean β :

$$P_f := \frac{1}{\sigma \sqrt{\pi}} \frac{\sqrt{2}}{2} e^{\left(-\frac{(B-\beta)^2}{\sigma^2} \right)} \quad \text{AV.25}$$

In words, the above equation is saying that people's perception about the timing of the decline in their fecundity (here described by B) is distributed around a common value, β . People's imperfect knowledge of their fecundity, which leads to a "perceived fecundity", results in a spectrum of choices of the timing for having their babies, which depends on B . From the expression for the timing of birth presented above, for a given B the chosen timing of childbearing is given by:

$$Equal := Tb = \frac{\text{LambertW}\left(\frac{(1+A) e^{\left(\frac{A+1+\alpha B A (1+g)}{A}\right)}}{A}\right) A - A - 1}{\alpha A} \quad \text{AV.26}$$

Rearrange the above equation to obtain B in terms of Tb :

$$B := \frac{\ln\left(\frac{Tb \alpha A + A + 1}{1 + A}\right) + Tb \alpha}{\alpha (1 + g)} \quad \text{AV.27}$$

Replacing this expression for B into P_f , it is possible to obtain a probabilistic distribution of the timing of births:

$$P_{Tb} := \frac{1}{\sigma \sqrt{\pi}} \frac{\sqrt{2}}{2} e^{\left(-\frac{\left(\frac{\ln\left(\frac{Tb \alpha A + A + 1}{1 + A}\right) + Tb \alpha}{\alpha (1 + g)} - \beta \right)^2}{\sigma^2} \right)} \quad \text{AV.28}$$

Using the following parameter values

$$A := 10 \quad \alpha := 0.075 \quad \beta := 44 \quad \sigma := 6 \quad \pi := 3.14 \quad g := 0$$

it is possible to plot the probability distribution of the chosen timing by the whole population (see Figure 12).

Figure 12. The probability distribution of the timing of childbirth

Age-specific Fertility Rate

Figure 12 shows people's choice of timing for having babies. It is possible to obtain an expression for the age-specific fertility rates by including the desired number of children as well as the effect of the declining fecundity:

$$ASFR := P_{Tb} n f_{bio} \quad AV.29$$

where:

$$P_{Tb} := \frac{1}{2} \frac{\sqrt{2} e^{\left(-\frac{\left(\frac{\ln\left(\frac{Tb \alpha A + A + 1}{1 + A} \right) + Tb \alpha}{\alpha (1 + g)} - \beta \right)^2}{\sigma^2} \right)}}{\sigma \sqrt{\pi}} \quad AV.30$$

$$n := \frac{A w Tb}{(p_n + p_{ART} - \rho) (1 + A)} \quad AV.31$$

$$f_{Bio} := 1 - e^{(\alpha (Tb - \beta (1 + g)))} \quad AV.32$$

which leads to:

$$ASFR := \frac{1}{2} \frac{\sqrt{2} e^{\left(-\frac{\left(\frac{\ln\left(\frac{Tb \alpha A + A + 1}{1 + A} \right) + Tb \alpha}{\alpha (1 + g)} - \beta \right)^2}{\sigma^2} \right)}}{\sigma \sqrt{\pi} (p_n + p_{ART} - \rho) (1 + A)} A w Tb (1 - e^{(\alpha (Tb - \beta (1 + g)))}) \quad AV.33$$

Use the parameter values:

$$A := 10 \quad \alpha := 0.075 \quad \beta := 44 \quad \sigma := 9.5 \quad \pi := 3.14 \quad g := 0 \quad w := 0.97$$

$$p_n := 5 \quad p_{ART} := 0 \quad \rho := 0$$

to obtain a plot of the ASFR which matches the empirical data for Denmark, as depicted in Figure 13.⁷⁷

⁷⁷ Source: Eurostat (2002).

Figure 13. Behavioural model and empirical data (Denmark)

Appendix B. Issues for further research

The following pages provide an interpretive appendix to the Documented Briefing. It addresses some of the principal caveats to, and simplifications in the analysis susceptible of, further improvement, and develops a potential research agenda to reduce the scope and test the implications of these limitations. Throughout, the aim is not simply to complicate the model or the analysis it supports, nor to attain maximum generality. The appropriate level of simplification must balance:

- Efficient use of available data (taking into account coverage, quality, consistency and relevance).
- The questions addressed (for instance, an assessment of the impact of ART to date will not necessarily serve to assess its future impact – *even if policy remains unchanged*).
- The interests, knowledge and engagement of the audience.

The analysis and modelling were necessarily simplified and modular. One ‘generic’ caveat is that the impacts of ART derive from sectoral dynamics of various domains as indicated in slide on the (un)intended side-effects, including:

- The population domain, including fertility, demographics (especially, morbidity and mortality) and migration;
- The economic domain, from the individual or micro-level influences on fertility choices to macro-level consequences for productivity, public expenditure and economic well-being;
- The political domain, from policy choices directly affecting the availability of ART to political preferences regarding the level and allocation of public revenues and expenditures; and
- The cultural domain, including, for instance, attitudes towards family size, fertility timing and other aspects of reproductive behaviour.

The linkages may be among the domains, which are often more important than developments in the domains themselves. For instance (see below for more discussion), demographic cycles are influenced by economic incentives, affecting stability in each domain: if people delay having children to build careers and face increased expenditures for having those children (e.g. due to competition with other older and wealthier parents) coinciding with higher-than anticipated expenses for the care of elderly parents (again, increased by competition), the result will be further pressure to delay or reduce reproduction. The resultant impact on the age structure of the population may be that each succeeding ‘wave’ is larger, rather than smaller, than the preceding one. The very different productivity and demand profiles that result will in turn induce shifts in the composition and extent of consumption and savings.

The analysis is set against the backdrop of changes in all these domains – while it necessarily begins from *ceteris paribus* it should not necessarily stop there. The following sections extend the caveats, exploring some of the simplifying assumptions made in

relation to these domains and the possible future research issues arising. It should be noted that extensive literatures on demographics, fertility and economic growth also go beyond the present analysis by projecting changes in fertility, mortality and morbidity, taking account of economic growth and (especially in the endogenous growth literature) linking together the economic and population domains. The following suggestions are based on the implicit assumption that these models and results would be incorporated as a starting point.

B1. The population domain

Fertility

As mentioned, the analysis separates biological fertility and behavioural fertility. Childbirth is a stochastic result of specific actions; biological fertility can be thought of as the probability that a given set of actions (ranging from unprotected sex to ART) will result in childbirth, while behavioural fertility refers to the actions themselves. The analysis presented above separates and simplifies each one. As with the other caveats, this is rooted in both practical concerns (tractability and data availability) and the need for conceptual and expositional clarity. But it is reasonable to consider whether a more nuanced view might be useful. One argument is that we need to consider more detail; the impacts of ART on births and on societal costs and benefits depend on phenomena below this level of resolution. The other reason goes in the opposite direction: observed data combine the effects of biological fertility and choice, and there is no reason to suppose that they are independent. Note that the behavioural fertility impacts of ART affect fertile as well as infertile couples.

Just as the activities comprising behavioural fertility cover a wide range, so too do the associated probabilities. The likelihoods of fertilisation, implantation and the other steps in the process leading to childbirth are affected by the ages, genetic fitness and compatibility of the parents, diet and nutrition, timing and other factors. Most of these cannot be observed, so a more useful starting point is to consider a couple or a potential mother over a given period of time. The analysis above uses women as the unit of analysis, described by age and cohort. To go further, one should consider:

- Couples – more specifically, the pattern and duration of relationships and the likelihood of genetic compatibility. These are, in turn, affected by developments in other domains.
- Other demographic factors describing the partners. Some of these (e.g. weight, smoking, diet, stress, etc.) may directly affect biological fertility, while others (e.g. education, income/wealth, ethnicity, location, etc.) may affect the choice and frequency of behavioural fertility actions. Still others (e.g. number of other children) may affect both.
- A portfolio of policies and choices affecting fertility. These include non-IVF types of ART and contraception (which can increase the certainty of intentional delay). Also, the assessment of contraception has produced a range of useful models that can be adapted to enhance the analysis of ART.

In both data and analysis, these need to be framed in both cross-sectional and time-series terms. The cross-sectional dimensions affect the predicted fertility in terms of aggregate numbers of births because total expected fertility is a weighted average of the fertilities of a differentiated population. Even if one only wishes to predict total births, the implied relationship linking, say, average income to average births need not be one-to-one, especially if the individual relationships are not linear. To illustrate, suppose that the likelihood of a given woman having a child in a given year showed a U-shaped response to income: a given level of average income will produce relatively modest fertility if all the population has middling income, but much higher fertility if the same average income comes from a population comprised of poor and well-off people only. More importantly, the dynamics of fertility (how previous history affects future outcomes) and the impacts (in terms of societal costs and benefits) are every bit as sensitive to the *distribution* of births as to their aggregate number.

Time series analysis is also important at both population and individual levels. At the population level, changes in ‘environmental’ factors,⁷⁸ medical practice and technology, population density and any of the factors mentioned above will change fertility of people of given ages over time. Again, some of these factors (e.g. pollution, medical science and practice, etc.) affect biological fertility, while others (e.g. income, population density and aging, etc.) affect choices.

At the individual level, time affects both actual and perceived fertility. Ageing is the main driver, and is already taken into account to some degree. But prior behaviour (e.g. partner search, diet, drug use, etc.) and exposure to environmental factors affect current biological fertility. Prior experience, job prospects, education, etc. affect the desire to have children.

Uncertainty and information stand out as key factors. The aggregate analysis recognises unobserved heterogeneity in fertility (e.g. in the distinction between fertile and sub-fertile women). Of course, the more detailed the description, the smaller is this heterogeneity, but some residual stochastic element will always remain. Exactly the same is true at the individual level; women do not know their own fertility precisely, though conscious strategies (timing) and medical technology can reduce the level of this uncertainty. But ovulation is only necessary (not sufficient) for biological fertility, which is in any event spectral. Thus, a woman cannot know how likely she is to conceive today, let alone how rapidly her fertility is likely to decline over time. Both public information and personal experience can provide more information, so the behavioural decision problem has the character of a ‘bandit problem’⁷⁹ – in other words, a woman gathers information about her fertility by trying to conceive and must trade off the payoff to conception against the value of that information – in addition, conception may affect actual as well as perceived fertility.⁸⁰ The research required combines two elements: an explicit recognition of the

⁷⁸ Including pollution, but also diet, stress, etc.

⁷⁹ Named after the “2-armed bandit” – or fruit machine. The point is that each play of the machine offers a possible payoff and gives information about the underlying probabilities. However, it also changes the underlying state of the system.

⁸⁰ See for example: BBC (2006) Fertility predictor test launched. Wednesday, 25 January 2006. Available at: <http://news.bbc.co.uk/1/hi/health/4642698.stm>.

complexity of the informational problem (and the close linkage of information-gathering from fertility behaviour) and the ‘real option’ perspective surrounding fertility choices: each option should be considered in light of the future choices it permits or prevents (as with e.g. embryo screening or birth timing and spacing). In this respect, the analysis should consider selective use of ART at different stages in birth order: ART used to produce second children will likely have a different expected rate of success and lead to changes in family size.

Demographics

The analysis is based on recent single-decrement life-tables. To fully capture the societal costs, multiple-decrement life-tables should be used, supplemented if possible by morbidity data relating to disease. This can shed light on disease-specific health costs and on costs relating to early-childhood health costs likely to be influenced by ART and to produce measurable effects within the projection horizon.⁸¹ Beyond this, life-tables continue to evolve over time, and projected data should be used where available.

Beyond this technical issue, the primary connection comes via the impact of population-level changes associated with the so-called demographic shift and (as a medium-term consequence) the ageing population. As mentioned in the main report, the latter phenomenon creates an economic and policy base for a range of responses, which could include ART. It also produces other impacts (e.g. the allocation and fiscal soundness of public expenditures, changes in economic productivity, a shifting political balance, economic migration, etc.) whose impact on the context for ART policy is profound. Thus the modelling must take due account of these changes; the pace of demographic changes and their socio-political ‘rebound’ effects; and the differential pace and extent of change in different areas, countries and sections of the population.

Migration

Migration is an increasingly sensitive subject. In the present analysis, it could play figures in two specific roles.⁸² First, it can change the underlying fertility of the population and – primarily from the behavioural perspective but also (via the factors listed above) biologically. Second, as a response to the ageing population it changes the age distribution directly. Although relevant, this has not been a primary focus of this research.

B2. The economic domain

Microeconomics of fertility choice

As Appendix A makes clear, economic modelling of reproductive choice tends to be based on optimising behaviour. This does *not* mean that all people are assumed to make lifetime income calculations, or that they all evaluate risk or discount the future in the same,

⁸¹ For instance, an increasing proportion of IVF births within the birth cohort may affect the prevalence of e.g. diseases reflecting genetic or dietary factors (either directly via embryo screening or indirectly through changes in the economic and demographic characteristics of birth parents or the strength of connections between them and the medical establishment.

⁸² See also: Grant et al. (2004) op cit.

analytically tractable way. All empirical work, for instance, makes allowance for variations around the benchmark model. Among the key assumptions are the following. The analysis discussed in the slides (see: page 41) addresses the issue of deliberate delay, and thus focuses attention on the influence of economic incentives on optimising behaviour.

First, the decision about how many children to have and the timing and spacing of their births reflects preferences that are unlikely to stay fixed over time. By the same token, revealed-preference data (gleaned from actual activities or births) are likely to differ from stated-preference data (gleaned from surveys, focus groups, etc.). Particularly important in this respect are the rate of discount and the path-dependence effects. Young people are known to discount the future more steeply, and may thus make decisions (e.g. to have children) that they may later regret (e.g. wishing that they had delayed childbirth). While reductions in the perceived cost of delay (e.g. availability of ART) may reduce this lock-in effect, the extent of the change will depend on the salience of such costs – this requires empirical investigation. Path-dependence means that anticipated ideal family sizes may change as children are (or are not) born. In particular, direct economic factors (e.g. the opportunity cost of lost income) are as uncertain as individual (family) fertility, so recent experience can be expected to change ‘intended’ behaviour even if underlying preferences over certain outcomes do not change. Thus, a woman whose career prospects are uncertain may wish to delay childbirth until a more concrete picture emerges. Alternatively, a woman whose early fertility experience is disappointing may decide to wait until trying again. The point here is that both economic and fertility-related uncertainty are considered together, so that responses to changing circumstance can easily be nonlinear, non-monotonic or even discontinuous.

Second, decisions about childbearing in a career context have a ‘real option’ character. In particular, female career earnings (and job) profiles are reduced compared to men by employers’ (professed) uncertainty regarding the risk of childbirth. The costs of this insurance are shared among all women (according to labour economists) in the sense that the earnings of all are affected by perceptions relating to those who may be intended to have children. The problem is complicated by the fact that a woman’s attempts to have a child cannot be observed by the employer until they are successful. These factors make the efficient reallocation and management of this risk difficult. The availability of techniques for decreasing the expected time between deciding to have a child and childbirth (incorporating the increased chance of success) reduces the extent of this risk and can facilitate the structuring of suitable labour contracts. In other words, the value to a woman of a decision to have a child after a certain number of years is increased to the extent that this can be credibly signalled to the employer. The same goes for prospective fathers, in view of evidence on the differential earnings and career progression of fathers.

The post-natal costs of having a child are affected by the income(s) and age(s) of the parents. Older parents may have more savings set aside for these costs. This may reduce the costs of financing children’s education, etc. compared to borrowing or paying out of current income; on the other hand, it may result in higher levels of expenditure, especially through cohort effects (such as competition for ‘good’ schools, etc.). Changes in the level of public service or subsidy provision can also affect these decisions, as shown in the comparison of ART with child support pronatalist policies.

A further possibility offered by ART is the chance to change family spacing and size, with obvious (but unmodelled and largely unmeasured) implications for economies of scale and scope.

It goes almost without saying that the aggregate impacts must be derived from a sound consideration of the distributional effects. These include claims within the family (e.g. whether the couple have ageing parents, other siblings, etc.) and variations in the incidence of costs across the population.

Finally, in the microeconomic perspective childbearing, consumption and savings are all derived from the same calculation. The precautionary motive for savings, in particular, is likely to be affected by the availability of ART. Empirically, reproductive choices can be modelled using nested discrete choice models. The reasons are:

- Reproductive choices are inherently discrete – the observable consequences certainly are;
- Reproductive choices are nested within for example education and work choices;
- This framework deals with unobserved heterogeneity (including variations in fertility). The distribution of these unobserved aspects dictates the form of the equation.

To integrate the results of the fertility choice model (incorporating economic factors) with the biological fertility and demographic models, account must be taken of the uncertain and variable lags between choices and outcomes. A second-cut analysis would use the choice model to trigger a hazard-rate model of births obtained by combining an ‘intensity of effort’ measure from the choice model with biological fertility curves.

The main complicating factor concerns uncertainty. This has two aspects. First, as mentioned above, women do not know their own fertility with certainty and typically learn by trying. The inference process follows well-known stochastic decision models – the main point is that initial failure increases the subjective likelihood of success next time, but after a certain length of time, Bayesian revision assigns more probability to sub-fertility. In particular, having one child (or a miscarriage) will change the posterior belief in a discrete way. The second is that a decision to delay childbirth is itself uncertain; while ART can increase the odds of conceiving at any age – in particular at a later age – this increase comes on top of the uncertain ‘baseline’ fertility at that age. It should therefore be possible separately to model early and late demand for ART.

Mesoeconomics: labour market impacts

As mentioned in the previous section, earnings profiles (and thus the expected costs of reproductive decisions) currently reflect high and differential degrees of uncertainty faced by employers (and employees) and the legal as well as informational obstacles to writing ‘efficient’ labour contracts to internalise these risks. Current projections of economic effects do not adjust for changes in the level of uncertainty or – beyond inflation – for changes in earnings profiles. In the most sophisticated analyses of, for instance, the impact of the ageing population (OECD, Eurostat), there are adjustments for inflation and labour productivity. These should be adapted to the ART analysis, in two respects. The first is the change in available labour supply by mothers (and fathers); the second is the change in

aggregate labour supply and productivity over time due to changes in the population of new workers.

In addition, while near-term projections and assessments of impacts for low levels of ART uptake must be based on continuation of current trends, it is reasonable that widespread planning of family size, timing and spacing (whether via ART or through associated changes in societal norms) will change the structure of wage offers. One logical consequence is a rebalancing of pay in career occupations between pay for performance and pay for potential.

The current analysis follows much of the literature in anticipating a slowdown in GDP growth resulting directly from the aging of the population. This is not certain, however; particularly in a globalised economy linking countries at different parts of the demographic transition in increasingly ‘virtual’ productive activity, it is reasonable to anticipate both a reconfiguration of skill requirements to meet the characteristics of the working population and a reallocation of productive activity to realise age-related gains from specialisation. This process of specialisation – of adapting labour utilisation to make optimal use of the skills and energies of the population – may even be accelerated by the impact of ART if jobs provide incentives to capture and share human capital between younger and older workers.

Macroeconomics: sectoral balance, trade and public expenditure

The full analyses of the impacts of population ageing consider a wide range of factors affecting societal costs and benefits of changes in demographic structures, including changes in health status and health costs, changes in pension provision and the costs of old-age care, changes in the benefits of education (and thus on the level of skill formation, etc. These same analyses can usefully be applied to changes relating to fertility – a preliminary set of computations is reported in Slides 5-6. In some cases, only a different set of population projections is required. For other aspects (e.g. costs associated with education, labour force participation and health care for mothers and children) new data (and possibly new models are required).

Analysis of age-related expenditure shows that some expenses can be attributed directly to different age groups (e.g. neonatal care, long-term housing for the elderly, etc.). But the costs and welfare productivity of these expenditures are affected by the modality of provision: public vs. private finance, funded vs. pay-as-you-go, incident-driven vs. insurance-based, etc. In addition, as a component of demand increases, the levels of supply and price change; recently, the ageing population has spurred a growth in services devoted to the elderly, and increased competition has simultaneously changed price, quality and availability.

While these are expenses, they are also areas of productive economic activity. As with any other shift in demand, the full range multiplier effects should be factored into the analysis. Thus, employment in an age-related sector is nonetheless productive employment, taxes paid by, for example, teachers are contributions to general revenues, and medical advances prompted by, for example, a burgeoning neonatal population or the scope for embryonic screening are likely to have spill over effects in other areas.

Finally, a shift in the age structure of the population, let alone one that may change the balance of socioeconomic classes, is likely to have effects on the sectoral balance of the economy far beyond such direct ‘inputs’ as health and education. People of different ages eat differently, wear different clothes, use transport differently, take holidays at different times, etc. We can thus expect ART or any intervention that changes (the trajectory of) the population age-income distribution to produce further macroeconomic effects.

Whether the combined stimulant impact of job reconfiguration, extended economic activity and the additional (esp. service) demands of an aging population can overcome slowing productivity growth and increasing economic dependency is an empirical question. But it seems likely that changes to the evolution of age structure have an important role to play.

B3. The political domain

Recent literature has shown that changes in the population age distribution profoundly affect political decision-making around a whole range of policy issues. These certainly include the provision of for example IVF, whether as part of the NHS or through another programme, but also extend to those elements of public goods provision most directly affected (e.g. health care and education). To the extent that ART produces a juvenescence of the population (or smoothes the juvenescence as the ageing population dies out), it can be expected to influence the political trade-off between, say, long-term care for the elderly and primary education.

B4. The cultural domain

As access to ART spreads, societal norms regarding appropriate family size and spacing and around the propriety of ART itself, can be expected to shift. These cultural reinforcers have a strong effect on reproductive behaviour, as studies of teen pregnancy have amply demonstrated. Conceptual modelling⁸³ can demonstrate the sensitivity of this process to policy, social structure, and economic factors – and also indicate the “S-shaped” dynamics of change. These in turn can be modelled using nested discrete choice analysis.

As the role of ART in a population policy mix is considered, it will be necessary to undertake further research and analysis that address the issues described above.

⁸³ See for example: Young, H.P. (1993) The Evolution of Conventions. *Econometrica*, 61 (1), 57-84

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