Economic instruments and consumption

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Abstract

The project has three objectives: to build a macroeconomic model of the economy to help us understand and predict patterns of energy and resource use; to perform microeconomic studies of patterns of demand for individual goods; and to investigate the importance of consumption externalities in determining labour supply.

Existing models can account for trends in global energy use purely on the basis of firms' production functions, by assuming a high degree of substitutability between inputs. But they fail when confronted by further data, which show that household preferences cannot be ignored. We have only a vague description of these preferences, how they are formed, and how they interact with technology and policy to determine economic and environmental outcomes.

Our macroeconomic model will show how the effects of different policy measures reverberate through the economy. Preliminary results suggest that measures which increase the efficiency of low-energy consumption alternatives should be favoured as they lead to 'reverse-rebound'; as their price falls, consumers switch towards them, and thus away from more energy-intensive alternatives. And we should beware of supporting efficiency improvements in energy-intensive goods only affordable to the richest; reductions in their price may lead to backfire. Detailed studies of patterns of demand for individual goods will support the macroeconomic model, showing effects of specific policies, such as raising the cost of air travel.

The high-tax European socioeconomic model is blamed for lowering labour supply, a bad thing. But we will investigate the extent to which labour may be oversupplied due to a consumption race, implying that lower labour supply is a good thing. This would turn the 'double dividend' argument on its head: environmental taxes lead to lower labour supply, which is a spin-off benefit rather than a drawback!

1. Objective and research question

The overall objective of this project is to suggest effective instruments to help achieve the goals of the Swedish government—in particular with regard to climate and resource use—highlighting relationships between production, consumption, and polluting emissions.

In a simple neoclassical economic model with a single good, perfect markets, and exogenous labour supply, the nature of technology and quantity of capital determines both the value of production in a country, i.e. GDP, and the quantities of primary energy and resources used in the production process. However, in reality there are many goods which differ greatly in energy- and resource-intensity. Consumer preferences and economic instruments—as well as the nature of technology—determine the pattern of consumption across these goods, and hence have a large bearing on total energy and resource consumption. Furthermore, labour supply is also variable, and is affected by preferences and policy instruments. This also has an important bearing on total energy and resource use, since more labour supply means more production and consumption, and hence also more resource use.

Given this background, the project has three overall research objectives, the first two of which relate to consumption patterns, the third to labour supply. The first objective is to build a macroeconomic, general-equilibrium model of the economy to help us understand historical patterns of primary energy use, and to predict the effects of policy measures; the second is to perform microeconomic studies to understand patterns of demand for individual goods, and link the results to the macroeconomic model. The third research objective is to investigate the importance of consumption externalities in determining optimal labour supply, and again to derive policy conclusions.

The approach of the project is economic. The neoclassical economic approach is often characterized as narrow. However, it is in fact flexible, and can be adapted to deal with any set of assumptions about (for instance) preferences and how they are formed. The approach is better characterized as mathematical in the sense that it consists of taking assumptions about how agents in the market behave—as well as what technologies and inputs are available—and using them to derive exact quantitative predictions about how the economy as a whole will develop, potentially including its effects on the natural environment and natural resource stocks.

2. Current knowledge

In this section I first discuss facts regarding long-run global trends in energy consumption, and consumption of metals. I then show that there exists a series of models—the oldest of which were developed in the 1970s—which can account for the long-run trends in the data entirely on the basis of firms' production functions, by assuming a high degree of substitutability between inputs (labour, capital, and resources) in these functions. Consumer preferences play no role. However, I then show that these models fail when confronted by further data, and this failure demonstrates that it is in fact essential to account for household preferences when explaining long-run trends in resource and energy consumption, and also when predicting future trends and designing policy instruments. I conclude that agents' preferences are very important in determining overall levels of energy and resource use in the economy, which in turn are strongly linked to carbon emissions and other factors affecting environmental quality. However, we have only a vague description of these preferences, how they are formed, and how they interact with technology and policy to determine the allocation of resources in the economy.

2.1. Global and national trends

Over the last 200 years, the value of global output per unit of labour input has increased greatly. However, the value of global output per unit of primary resource inputs has not increased nearly so much, if at all. This seems surprising given the obvious increases in the energy- and resource-efficiency of individual production processes over the same period; normally we expect an increase in efficiency to result in an increase in output per unit of input.

Figure 1—showing data on production, energy use, and price—suggests that although the short-run elasticity of substitution between energy and the other inputs to production is small, the long-run elasticity is close to 1, implying that the long-run energy share of GDP is constant. Furthermore, both Griffin and Gregory (1976) and Pindyck (1979) use cross-section data across countries and estimate an own-price elasticity of energy use of 0.8, and Griffin and Gregory explicitly consider the Cobb–Douglas function and cannot reject it. If we assume that price differences between countries are persistent this supports the idea of (close to) unit long-run elasticity. Note that Figure 1 shows primary energy from combustion. It does not include energy from food and animal fodder, neither does it include nuclear power and renewables.

Similar data on global metal consumption (in tons per year) and price (in constant USD per ton, weighted across all metals) gives rise to a similar picture (not shown here): the weighted price of metals is the same in 2000 as it was in 1900, whereas the total rate of extraction and consumption of metals has increased in line with global product.

2.2. Existing models: DHSS, Atkeson and Kehoe, DTC

A very simple and standard model in economics, the neoclassical growth model adapted to include resource inputs, is broadly consistent with the data showing that the factor share of resources is constant. (This model is often known as the DHSS model, named after the

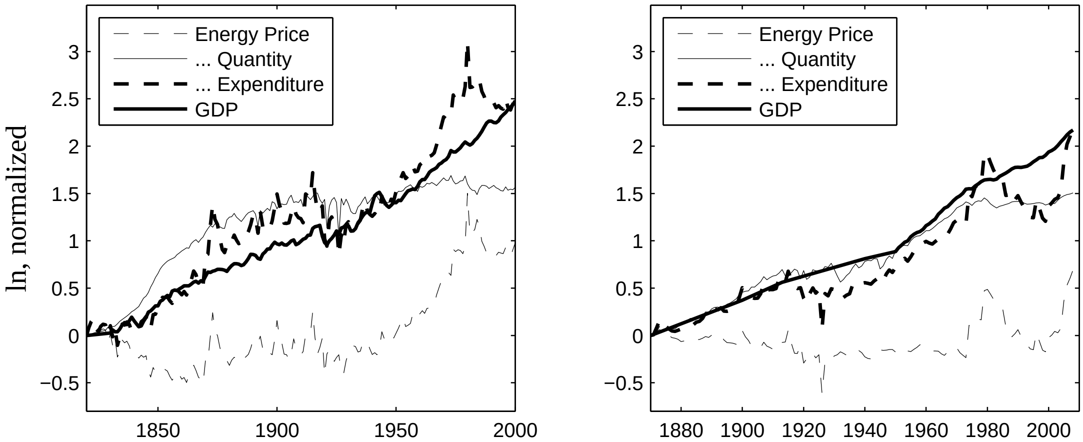

Figure 1: Long-run growth in consumption per capita and prices, compared to growth in GDP per capita, for primary energy from combustion: (a) U.K.; (b) Globally.

Global product data from Maddison (2010). Energy: Coal, oil, natural gas, and biofuel. Global fossil quantity data from Boden et al. (2012); UK data from Warde (2007). Oil price data from BP (2012). Coal and gas price data from Fouquet (2011); note that these data are only for average prices in England; we make the (heroic) assumption that weighted average global prices are similar. Biofuel quantity data from Maddison (2003). Biofuel price data from Fouquet (2011); again, we assume that the data are representative for global prices, and we extrapolate from the end of Fouquet's series to the present assuming constant prices. Combustion of biofuels in the U.K. is negligible over the entire period. Sensitivity analysis shows that the assumptions are not critical in driving the results.

papers of Dasgupta and Heal (1974), Solow (1974a,b), and Stiglitz (1974).) Essentially all that we need to make our point here is the production function most commonly used in this framework, the Cobb–Douglas. That is, the resource R, capital K, and labour L are combined to produce a single product (we call it a widget) according to the following function:

$$Y = (A_R R)^{\alpha} (A_K K)^{\beta} (A_L L)^{1-\alpha-\beta}.$$

Here α and β are parameters and A_R, A_K, and A_L are productivity factors. Assuming perfect competition between firms, each with this production function, we find that whatever the trend in w_r (the resource price), the share of firm costs accounted for by R (i.e. $w_r R/Y$) remains constant. The reason is the unit elasticity of substitution between resources R and the other inputs, capital and labour. So (loosely) if the price of resources rises by 1 percent the quantity declines by 1 percent, and the cost share remains the same.

The substitutability between inputs on the production side has been questioned, since the data show that short-run demand is inelastic, suggesting a low degree of substitutability between inputs in the short run. This can be explained without too much difficulty, either by assuming that capital investments lock firms into patterns of input use in the short run (Atkeson and Kehoe, 1999), or by assuming that inputs are used in fixed proportions relative to one another for any given technology, but that these proportions can change over time due to a process of directed technological change (DTC) which makes scarce inputs more productive. In the standard approach to modelling DTC (see for instance Acemoglu, 2002) investment in knowledge augmenting different factors is in proportion to the shares of those factors. Since energy is complementary to labour–capital, when energy price increases its share also increases, hence energy-augmenting knowledge is boosted, pushing the energy share back down. Hart (2013) shows that if the factor-augmenting knowledge stocks are produced independently of one another—denoted *independent knowledge stocks*—then this buffering mechanism is perfect in the sense that the long-run factor shares of complementary inputs are independent of the quantities of these inputs: that is, the long-run production function is Cobb–Douglas! In the light of this result it is not surprising that the seminal paper in the modelling of DTC and energy demand—Smulders and de Nooij (2003)—implicitly assumes independent knowledge stocks, thus yielding the long-run fixed-share property. Many subsequent authors—including Gerlagh (2008), Fischer and Newell (2008), Gans (2012), and Hassler et al. (2012)—make the same assumption and thus their models have the same property.[1]

Neither the explanation based on capital vintages, nor that based on DTC, stand up to scrutiny. The problem with the idea that capital investments lock firms into input patterns in the short run is that this presupposes the existence of a menu of alternatives with widely differing input requirements to produce the same good. So, for instance, it we want to make a car we can either use lots of labour and capital and little steel, or little labour and capital and lots of steel. Of course there is a degree to which extra labour can contribute to more efficient use of steel inputs such that more cars can be made per ton of steel used, but this effect seems likely to be marginal. The explanation based on DTC seems more promising: the amount of steel needed to make a given type of car might be more-or-less fixed at a given time, but given technological progress we can find ways of making cars with the same or better quality (performance, safety, etc.) with less steel. And if the price of steel is high then a lot of effort will be put into finding such technologies.

The problem with the DTC-based explanation for increased resource and energy use is that study of the data shows that technological progress has in fact strongly favoured lower levels of resource use in the production of given products, especially in the case of energy. But this improvement has not been reflected in aggregate increases in the value of production per unit of primary energy input. To see this we consider two products, artificial light and motive power. Light is a convenient product category for analysis since light is a consumption good which is rather homogeneous and unchanging over very long timescales, and the energy efficiency of its production is easily measured. Fouquet and Pearson (2006) study light production and consumption in the U.K. over seven centuries. They conclude that the efficiency of light production in the U.K. (measured by lumen produced per watt of energy used) increased 1000-fold from 1800 to 2000; the productivity of labour in the U.K. over the same period rose by a factor of 12–15 (estimates vary). Light production is a convenient sector within which to measure efficiency, but it is not very large. Now we turn to the production of motive power from fossil fuels, a very large sector. In the 19th century motive power was largely generated by steam engines, while over the last 100 years we must consider electric power generation and the internal combustion engine. Regarding steam engines, sources such as Hills (1993) suggest that their efficiency in generating power from coal inputs increased steadily from their invention in the early 1700s up to 1900, and by a factor of around 20 over the entire period; this growth in efficiency is again more rapid than the growth in labour productivity over the same period. Subsequently, the efficiency of coal-fired power stations has continued to increase but at a declining rate; see for instance Yeh and Rubin (2007) for detailed evidence. Regarding the internal combustion engine, Knittel (2011) shows that—for a vehicle of fixed characteristics in terms of weight and engine power—fuel economy would have increased by 60 percent over the period 1980–2006 due to technological change, corresponding to a growth rate of 1.8 percent per year, slightly greater than the average growth rate of labour productivity over the same period, which was 1.7 percent per year.[2]

The above explanations (DHSS, Atkeson and Kehoe, DTC) for the constant cost share of energy and resources—and hence the failure of decoupling—are all based on firms being able to substitute between inputs used in the production of a given representative product. When the price of resource or energy inputs falls relative to the prices of alternative inputs, firms use relatively more of the resource. And the fall of resource price relative to the wage then explains why firms use more and more resources. However, they fail because we cannot find evidence for this substitution process actually occurring to the extent required: indeed,

[1] In the case of Smulders and de Nooij (2003) the fixed-share result seems paradoxical, as the authors set out to explain why the energy share has *declined* in recent decades in a selection of countries. The explanation is that the authors start off their simulated economy away from the long-run balanced growth path (b.g.p.), and the decline in share occurs on the transition path.

[2] We calculate this figure using data from stats.oecd.org, Labour productivity growth in the total economy.

we see the opposite, that firms have become more and more resource efficient in the production of given products.

So if the above explanations cannot account for the failure of decoupling, what can? Put differently, if resources and labour–capital are not highly substitutable in the production of given products, why is it that increases in the efficiency with which we can use resources to make products are not reflected in lower total energy use per unit of production? The answer must lie on the consumption side of the economy: there is more than one product made in the economy, and consumption patterns across the available products shift over time.

2.3. The role of households and their preferences

Preferences and consumption patterns. Firms have become more efficient in converting given resource and energy inputs into given products, but average resource and energy use per unit of production has not increased. The explanation must lie in a countervailing shift in consumption patterns over time, towards products which are resource- and energy-intensive. Such a shift must be driven by the nature of household preferences. We know that households have got richer, while energy-intensive products have got cheaper relative to other products. So there are two obvious candidate explanations: a substitution effect towards energy-intensive goods driven by changes in relative prices, and an income effect, which would apply if energy-intensive goods are luxury goods, i.e. disproportionately favoured by high-income households.

A natural first question is to ask how wide are the variations in resource and energy intensity across products and sectors. In Figure 2(a) we see that if we divide consumption into two equal parts, one energy-intensive the other not, then the low-energy-intensity consumption accounts for just under 20 percent of energy consumption. In 2(b) we see the energy intensity and expenditure share of different consumption categories: different types of services —of low energy-intensity—account for more than half of expenditure, while the two major energy-intensive categories are habitation and motor transport, and the final category (with highest intensity but only a small expenditure share) is air transport.

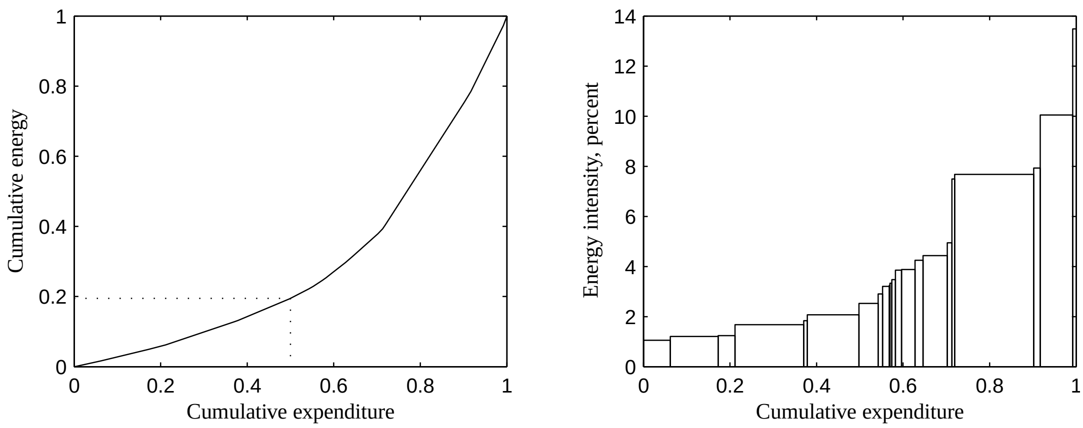

Figure 2: Cumulative energy use and energy intensity plotted against cumulative expenditure when consumption products are sorted in order of increasing energy intensity. All the axes are normalized. Regarding energy intensity, we only have data on relative intensities, and we normalize to give an average intensity of 4 percent.

Data from Mayer and Flachmann (2011). The products—in order of increasing energy intensity—are Education services; Health services; Health services and social work; Other services; Cultural and sport services; Retail and wholesale trade; Hotel and restaurant services; Office and electrical machinery; Paper and publishing; Water transport; Auxiliary transport services; Other land transport; Furniture, jewellery, musical instruments etc.; Other products; Textiles and furs; Food and tobacco; Agricultural products; Transport via railways; Habitation; Chemical products, rubber, and plastic; Motor transport; Air transport.

Given significant differences in energy-intensity across products, shifts in consumption patterns (also known as *structural change*) have the potential to drive increases in energy use. Note that structural change may include shifts to completely new products, and between alternative products within the same sector (such as transport). There is a vast and varied body of evidence showing the importance of structural change for energy demand. Direct evidence based on recent data is provided by Knittel (2011), as described above. The efficiency improvement demonstrated by Knittel leads to a fall in the cost of extra weight and power in a new car; at the same time we see consumers choosing cars of increasing weight and power. This structural change could be the result of a substitution effect (i.e. the fall in the relative price of running a heavy and powerful car), an income effect (i.e. richer consumers choosing heavier and more powerful cars), or some other effect, such as a change in preferences. For a more extreme example consider the consumption of light: Fouquet and Pearson (2006) find that per capita consumption of artificial light in the U.K. rose by a factor of 7000 between 1800 and 2000. This factor should be compared to the approximately 15-fold increase in per capita GDP over the same period; without shifts in consumption patterns, consumption of all products should have risen by this factor over the period.

Another type of structural change is the shift over time towards consumption of products which did not previously exist, typically accompanied by an expansion in the total variety of products consumed. Consider for instance the transport sector, where new products introduced include trains, automobiles, and passenger aircraft. Crucially, the new products are typically more intrinsically energy-intensive than their predecessors.

There is a body of research on structural change and capital-intensity. For instance, Acemoglu and Guerrieri (2008) model substitution between labour and capital with the aim of explaining both the constant capital share and structural change. Furthermore, Boppart (2014) models the same question with a model where the focus is on consumer preferences and income effects as the economy grows. Furthermore, there is a large amount of research on what has been dubbed the 'environmental Kuznets hypothesis', where the idea is that increasing income leads first to an increase in polluting emissions, but subsequently a decrease (see for instance Dinda 2004 for a survey). However, the explanatory and predictive power of this work has been questioned, since it tends to build on econometric estimations not backed up by structural models of the driving forces behind the trends.

Preferences, labour supply, and growth. Two areas which are ignored in the economic analyses of long-run resource and energy use cited above are long-run growth and labour supply. That is, both are treated as exogenous, with long-run growth driven by exogenous technological change, and labour supply depending only on exogenous population growth.

Growth is a function of investment, which is linked to households' trade-off between consumption today and consumption tomorrow. If households are patient—and hence very willing to make sacrifices today to gain future rewards—then investment tends to be higher, and thus also the growth rate. The effect of higher growth depends of course on the consequent changes in resource efficiency in production, and consumption patterns.

Labour supply per capita is also in reality a variable that can be affected by policy choices. The norm in the economic literature is to assume that labour tends to be *undersupplied* in a regulated market economy compared to what would be socially optimal, primarily because of the need to impose taxes on labour income which reduce the incentive to work; see for instance Keane (2011). (The reason that taxes are imposed is of course in order to provide public goods such as law and order and national defence, as well as—in many countries—health care, education, and social security.) However, another strand of research suggests that labour may in fact be *oversupplied*, due to consumption externalities. The idea here is that household utility depends not just on own consumption, but also that it is a decreasing function of the consumption of others. The utility that an agent gets from a fixed quantity of consumption therefore varies over time if the consumption levels of other agents vary. One of the first papers in this field is Boskin and Sheshinski (1978), who investigate an economy in which agents' preferences are such that an agent's utility depends not just on her income level, but also on her income *relative to the other agents in the economy*: the higher is relative income, the higher is utility. This can lead agents to compete with each other in allocating their resources to activities which raise their incomes, relative to other activities which do not. For instance, in Aronsson and Johansson-Stenman (2013) agents may allocate their time to paid work instead of leisure to get ahead in the rat race, but since everyone does the same, no one actually gets ahead. The result is a coordination failure or negative externality, and if all agents could coordinate to work less and take more leisure then all would enjoy higher utility. One way to achieve such coordination is through an income tax redistributed lump-sum or in the form of public goods such as education, health care, and environmental quality. Similar effects may also apply when consumers compare their income with the income of consumers in other countries, as shown by Aronsson and Johansson-Stenman (2014). Here we have both the consumption externality and a global public good, and the conclusion is that the existence of the consumption externality (each country wants to be richer than the other countries) makes it harder to agree on provision of the public good.

2.4. The effect of policy

How can policy affect consumption patterns to diminish the negative effects of Swedish consumption on health and the environment? We tackle this question in two stages. First we review recent research in Sweden, then we tackle the same question from the perspective of the proposed research project.

Recent research in Sweden. A good starting point in summarizing recent research in Sweden is Mont and Plepys (2008). They differentiate between the approaches typically taken within different disciplines, such as economics, sociology, and psychology. Their focus is on how preferences are formed: within economics there has been little interest in this question in the past, but now ideas from sociology and psychology are gaining ground within economics. Sociological studies, according to Mont and Plepys (2008), focus on how institutions—family, religion, the educational system—affect consumption patterns, whereas psychological research focuses more on emotions and habits, and underlying attitudes and motivations.

Given this research foundation, what policies have been enacted? There are a range of economic instruments, mainly but not exclusively directed at producers (but affected consumers via the market mechanism). In addition, a range of policies regarding information—such as eco-labels—are intended to affect consumers directly. The 'information' approach has recently received a lot of attention, thanks partly to the book 'Thinking, fast and slow' of Daniel Kahneman (2011). In particular, a popular idea is that tiny but carefully planned signals from the government or other agents (so-called *nudges*) might have significant effects on consumer choices. However, there remains a lot of uncertainty about how much is actually achieved through such measures.

One area is—according to Mont and Plepys (2008)—notable for a *lack* of policy action, and that is government strategies to challenge the assumption that society benefits when the government's primary aim is for material economic growth, and that this is supported by a materialistic consumer culture. Ideas around alternative societal goals based around ideas such as *sufficiency* remain at best marginal in policy discussions.

We now turn to two very recent reports, Hennlock et al. (2015) and Larsson (2015). Hennlock et al. evaluate policy instruments which are directly applied to consumers, and which have an environmental goal or perspective. Furthermore, they report on existing evaluations, so where these are lacking they are unable to comment. The authors thus point out that many policies which do have effects on consumption—including general taxes such as VAT and income tax—fall outside their remit. Of those which they study they find that congestion charges, carbon-dioxide-differentiated vehicle tax, and the green car rebate have had clear and significant effects on consumption patterns. Effects of other measures—such as in the housing and food sectors—are smaller and harder to demonstrate. They call for an inclusive approach to the analysis of economic instruments which includes instruments directed to producers and retailers as well as consumers.

Larsson (2015) investigates alternative scenarios for Swedish emissions of greenhouse gases, arguing that 'radical changes are needed regarding road transport, food, aviation and the global energy system (p.10). Regarding food they argue that a lot could be achieved by a change in people's diets (away from meat), and for air transport they show that eco-efficiency improvements are unlikely to be sufficient to meet long-run climate goals, if consumption continues to grow as predicted.

The approach of the proposed project. We know that structural shifts towards energy and resource-intensive goods have occurred, and have been important in driving increases in energy and resource consumption despite increases in the resource-efficiency of individual products. These facts suggest that structural change is also likely to be important in the future, and hence if we want to manage future outcomes we need to be able to understand and predict these processes.

Nevertheless, theories learned in first-year economics suggest that we do not need to distinguish between production and consumption, even in the presence of structural change. The argument has two parts. Firstly, it is a standard result that given a competitive market a tax has the same effect whether it is applied to the producer of a good or the consumer at the point of sale; the same applies to an environmental or *Pigovian* tax. Secondly, we know that if a market is perfect with the exception of the existence of an environmental externality, and where emissions are measurable and the damages caused are independent of the timing or location of the emission, then the best instrument is one that prices emissions, such as a Pigovian tax. The reason is that the market then determines the allocation of abatement measures, resulting in any given level of abatement being achieved at minimum cost. Putting these two parts together we conclude that emissions should be priced at marginal external cost, irrespective of the nature of (for instance) household preferences.

However, first-year economics is not the same as cutting-edge research, and in reality we know that the above analysis does not hold, for at least two reasons: firstly, even when there is only one market failure it may not be feasible to correct it by pricing emissions, and given second-best strategies such as research subsidies it is essential to model both production and consumption; and secondly there are typically multiple market failures requiring multiple regulatory instruments, and some of these failures may be directly related to household (rather than firm) decision-making.

The above analysis leads us naturally to the conclusion that we need a *general equilibrium* analysis of the economy in order to properly investigate the effects of policy measures, that is an analysis which includes knock-on effects of a given policy measure throughout the economy. A good illustration of this is if we consider the *rebound effect*, which is the reduction in gains from a technology that increases the efficiency of resource use, because of general-equilibrium effects. Assume for instance that—in some economy—air transport uses 100 GJ of energy per year, and that a policy to subsidize research yields an increase in the efficiency of aircraft engines by 10 percent. Does total energy use in the economy fall by 10 GJ? Almost certainly not, for several reasons. The fundamental reason is that the fuel saving makes the provision of the total sum of goods and services in the economy cheaper, so there are inputs (labour and capital) left over which can be devoted to other forms of production and subsequent consumption. Furthermore, relative prices and incomes also change, so consumption patterns may also change as a result of the efficiency increase. The evidence for rebound effects is reviewed by Sorrell (2007), who finds that they are significant but generally much less than 100 percent, implying that increases in energy efficiency of specific products do lead to large reductions in energy use associated with consumption of those products. A key reason for this is that the substitutability between energy-intensive and other products is far from perfect, just as intuition would suggest.[3]

Another example of the need for a general-equilibrium approach comes when we consider ideas connected to green consumerism. Consider for instance the idea that consumers should be persuaded—perhaps through nudges—to switch to organically produced food, based on the idea that organic production leads to lower emissions of pollutants per unit of land. This may be true, but on the other hand we know that it also yields lower production of food per unit of land, and if we assume that the quantity of food purchased is unchanged then more organic production definitely means more cultivated land, and it may also mean a higher total quantity of pollutants. But it does not stop here: organic production presumably involves

[3]For the first analysis of rebound see Jevons (1865), and for another useful presentation see Binswanger (2001).

greater inputs of labour per unit of produced food, and if total labour supply in the economy is fixed then this implies that labour shifts from the non-farm sector into the farm sector, which reduces polluting emissions in other sectors! Finally, the idea that total labour supply may also vary as a function of policies or nudges from the government further underlines the need for general-equilibrium analysis.

Finally, the presence of international trade also leads to the conclusion that national policy cannot solely be applied to producers, if we also accept a share of responsibility for what we consume. Since approximately 50 percent of what we consume in Sweden is imported (in value terms), policies tackling the energy- and resource-efficiency of producers will only tackle half of the overall problem.

3. Theory and method

I now explain in detail the planned research within the project. Recall that there are three overall research objectives, the first two of which relate to consumption patterns, the third to labour supply. I now discuss these in turn.

3.1. A macroeconomic model of past and future consumption patterns

The first objective is to build a macroeconomic, general-equilibrium model of the economy to help us understand historical patterns of primary energy use, and to predict the effects of policy measures. This will build on preliminary work which is already well advanced; see for instance Hart (2015).

Preliminary results

The key to the work is a macroeconomic framework which encompasses expanding variety of products, variation in the energy-intensity of products, and substitution and income effects on the consumption side. The end result should be a model capable of explaining historical data and making predictions about the future, including the effect of different policy measures.

In preliminary work, partly described above, we show that directed technological change —leading to slow growth in energy-augmenting knowledge—is not responsible for the failure of the energy share to decline despite the long-run decline in the price of energy relative to labour. Our second claim is that this shows that a shift in consumption patterns over time towards goods of high energy intensity must be an important part of the explanation. We propose a novel model in which the switch consists not just of increasing consumption of existing energy-intensive goods, but also the production and consumption of completely new such goods. The switch is driven by a combination of income and substitution effects.

In the model we assume that there exists an infinite continuum of possible goods—indexed by i—which are made in a Leontief production function using labour l and resources r, each with associated productivities A_l and A_r:

$$y_i = \min\{A_{li}l_i, A_{ri}r_i\}.$$

Now assume that labour productivity $A_{li} = A_l$, i.e. it is equal across all the goods. However, energy productivity A_{ri} is a declining function of i, A_r/i. And that A_l and A_r evolve exogenously. This amounts to assuming that we have a range of goods which differ in the amount of energy needed to make them, with the most basic good ($i = 0$) needing only labour.

Now be set up a utility function which implies that consumers prefer to consume a range of goods, but are not bound to consume positive quantities of each good; $\bar{y}$ is a constant factor which ensures that no good is essential even though the goods are complements:

$$u = \left[\int_0^\infty [(y_i/L + \bar{y})^{-1} - \bar{y}^{-1}]\mathrm{d}i\right]^{-1}.$$

So goods with high i are more energy-intensive, more expensive, and hence consumed in smaller quantities or not at all.

For a given energy price and technology levels we can solve this model to show which goods are made, and in what quantities. Furthermore, we can calibrate to model so that when we let A_r, A_l, and w_r/w_l change over time to reflect actual historical trends, the model predicts rates of energy consumption which match observations.

In the model economy, policy-induced rises in the price of energy will reduce energy consumption, as will policy-induced increases in the growth rate of energy-augmenting knowledge. However, technology policy is more effective if it can be directed towards goods which lie towards the lower end of the distribution of energy intensities. The reason is that an increase in the energy-efficiency of such goods causes their price to decline (albeit weakly), inducing consumers to substitute towards consumption of these goods. The resulting drop in consumption of energy-intensive goods leads to a 'reverse-rebound' effect: an increase in energy-augmenting knowledge in production of good i, A_{ri}, by a factor x leads to a reduction of total energy consumption R by *more* than $R_i(1-1/x)$. On the other hand, somewhat paradoxically, increases in the energy-efficiency of the most energy-intensive goods (such as air transport) are much more likely to lead to rebound or even backfire, i.e. an increase in total energy consumption. Because these goods are assumed to be on the cusp of affordability, their price elasticity of demand is extremely high.

The model predicts that if the energy price tracks the wage in the future, this will brake the growth in energy consumption but not stop it. Such an increase in w_r could be cancelled out if energy efficiency A_r stops rising. This is bound to happen in some sectors, such as lighting and motive power, where the laws of physics impose strict limits on what is achievable, limits which we are already approaching. This points to the need for new models of directed technological change which base the innovation possibilities frontier on evidence rather than assumption (*cf.* Hart (2013) and Nordhaus (1973)). In the most pessimistic scenario—with long-run growth but a slowdown in growth of energy efficiency—the model would predict that the relatively stable global energy consumption since 1974 may be only a temporary phenomenon, with consumption set to rise again in the future.

The model includes both price and income effects in the explanation of consumption trends, and the two effects have roughly equal weight. The most optimistic scenario is that the model underestimates the role of income effects in explaining the historical data, and that energy-intensive products are luxury goods at low and middle incomes, but inferior goods at high incomes.

Planned research

The first part of the planned research is to continue development of the preliminary model described above, in three directions: firstly, to complete and publish the draft paper, where the main aim is to address the existing literature regarding modelling long-run energy demand, such as Atkeson and Kehoe (1999) and Smulders and de Nooij (2003). This paper will be submitted to a mainstream economics journal such as the *Journal of Economic Dynamics and Control*.

The second direction in which the preliminary model will be extended is in a paper directly addressing the rebound effect and the rebound literature. There is a severe lack of research investigating rebound effects in a fully developed general-equilibrium context. Recall that evidence for rebound effects is reviewed by Sorrell (2007), who finds that they are significant but generally much less than 100 percent, implying that increases in energy efficiency of specific products do lead to large reductions in energy use associated with consumption of those products. A key reason for this is that the substitutability between energy-intensive and other products is far from perfect, just as intuition would suggest. This evidence suggests that rebound alone cannot explain the shift towards consumption of energy-intensive goods, implying that income effects (driven by rising labour productivity) must also have a part to play. Although microeconomic studies of rebound abound, there have only been a few attempts to build macroeconomic models in the literature: see for instance Saunders (1992, 2000).

In some of the empirical work which attempts to account for general equilibrium effects there are unexplained and paradoxical results. For instance, Brännlund et al. (2007) suggest that energy-efficiency improvements in the two most energy-intensive sectors (transport and heating) lead to only small substitution effects towards consumption in these sectors. Nevertheless, the overall rebound effect is so powerful that we actually observe backfire, i.e. an increase in total energy use. This result is paradoxical since the only way to obtain backfire should be through a very large shift in consumption patterns from low-energy to high-energy sectors, but this shift is explicitly stated to be small by Brännlund et al..

The preliminary work described above shows that rebound effects of increased energy efficiency of given products are equally likely to be negative as they are to be positive: when products of lower-than-average energy intensity become more energy efficient, substitution towards these products causes an additional reduction in energy use compared to the baseline. On the other hand, when products are both very energy-intensive and on the cusp of affordability (consider supersonic passenger flight, or space tourism) then increases in energy efficiency may have very large positive rebound effects, i.e. powerful backfire, as consumption moves towards these products from less energy-intensive alternatives.

Another area crying out for a thorough macroeconomic analysis is the rebound effect of changes in preferences. Here the work of Grabs (2015)—based on a Master's thesis supervised by the application—is relevant. As in Brännlund et al., the re-spend of money saved through the change is crucial. A switch to low-carbon consumption within a given sector is typically also a switch to *cheaper* consumption within that sector, and it is crucial to investigate what the consumer does with the money 'left over'. If it is re-spent on high-energy goods we may have backfire; on the other hand, if the consumer chooses to reduce labour supply (and hence income) then the positive effect of the change is unambiguous.

The third direction in which the model will be extended is to improve and deepen the analysis. The model should be improved both on the production and the consumption sides. On the production side, the production function should be generalized, for instance to include capital as well as labour and energy. This could have a very important effect given that capital and energy inputs are often strongly complementary. On the consumption side the model should be generalized to allow for a range of consumers with different incomes. Here the theoretical work by Boppart (2014) will be adapted to the analysis of energy; Boppart develops a general-equilibrium model with non-Gorman preferences (i.e. where differences between consumers have an important effect on consumption patterns) to explain patterns in the shares of capital and labour over time. Furthermore, results from the second part of the overall project (described below) will be used to parameterize and test the model. The goal is to develop a model which can explain and predict demand patterns on a country-by-country basis, thus testing (for instance) the idea that the leading economies are in the early phases of a de-industrialization process that will lead to lower demand for energy- and resource-intensive products.

Boppart (2014) assumes, on the consumption side, PIGL preferences over labour- and capital-intensive goods. In the planned research we would assume the same preferences over labour- and energy-intensive goods, as follows:

$$U_i(0) = \int_0^{\infty} \exp[-(\rho - n)t] V(P_L(t), P_E(t), x_i(t)) \mathrm{d}t,$$

where P represents price, x is expenditure, and V is an indirect utility function, which has the following form:

$$V = \frac{1}{\varepsilon}\left[\frac{x_i(t)}{P_E(t)}\right]^{\varepsilon} - \frac{\nu}{\gamma}\left[\frac{P_L(t)}{P_E(t)}\right]^{\gamma} - \frac{1}{\varepsilon} + \frac{\nu}{\gamma},$$

where $0 \leq \varepsilon \leq \gamma < 1$, and $\nu > 0$. Then it follows (after some work) that

$$\chi_L^i(t) = \nu \left[\frac{P_E(t)}{x_i(t)}\right]^\varepsilon \left[\frac{P_L(t)}{P_E(t)}\right]^\gamma, \tag{1}$$

where χ indicates the share. So $\chi_E^i + \chi_L^i = 1$. Given that ε is positive, equation 1 implies that the share of labour-intensive goods is declining in the expenditure level, which is what we observe in the data. Taking logs we have

$$\log \chi_L^i(t) = b(t) - \varepsilon \log x_i(t).$$

So given data on shares for different deciles, and in different years, we can estimate ε. Note that $b(t)$ is then treated as a time-dependent intercept.

If we have aggregate data on prices and expenditure then we can use equation 1 to estimate the following equation:

$$\log \chi_L(t) = \log \nu + \varepsilon(\log P_E(t) - \log X(t) + \log L(t)) + \gamma(\log P_L(t) - \log P_E(t)),$$

thus obtaining estimates for both ε and γ. If we prefer our previous estimate for ε then we can take that as given and use the new data to estimate γ (given ε). We have thus fully characterized the model of consumer preferences, and can use the model to explain past observations and make predictions about future trends given different scenarios for future growth and relative prices.

The initial idea is to focus on the car sector—on which we can obtain household consumption data from SCB—and take it as representative for the whole. In further work we would include further sectors. In the car sector we would use data on the following:

- Average fuel price by year, denoted P_F;
- Total fuel quantity by year, denoted Q_F;
- Total distance travelled by year, denoted D.

If we can also construct data on the average power output of the car fleet, H, then we can construct a measure of transport services. This could be for instance $D \times H$. The price of transport services would then be

$$P_E = P_F Q_F / (DH),$$

and the share of these services would be

$$P_F Q_F / Y.$$

However, we want transport services to be representative for all energy-intensive services. So we scale up by a fixed factor θ, and choose θ to match the SCB data for 2012; call the energy share in 2012 Z.

$$\chi_E = \theta P_F Q_F / Y.$$

The share of labour χ_L is of course $1 - \chi_E$. For the price of labour services P_L we simply use the fact that average prices are constant. Assume a basket in which a proportion Z of expenditure goes to energy services, and $1 - Z$ to labour services. Then, given real prices (zero inflation), the cost of the basket must be constant. So

$$P_E Z + P_L(1 - Z)$$

is constant. So if for instance P_E increases by i percent, then P_L must decrease by $P_E Z / [P_L(1 - Z)] \cdot i$ percent.

3.2. *Microeconomic studies of rebound effects*

The second research objective is to perform microeconomic studies to understand patterns of demand for individual goods, and link the results to the macroeconomic model.

Preliminary work. Preliminary work in this area consists of two Master's theses that I have supervised, Grabs (2014) and Leander (2015), where the former has also led to a journal publication, Grabs (2015). Grabs (2015) shows that a change in preferences such that consumers switched to vegetarian diets would, ceteris paribus, lead to positive savings both in the energy use and the greenhouse gas emissions linked to the consumption behaviour of an average Swedish consumer. However, the vegetarian diet would be cheaper, and the econometric results suggest that re-spend of money saved would almost exactly negate the effects on energy consumption. In the light of the preliminary work described above, this is not a surprising conclusion; since food production is of roughly average energy-intensity, if consumers spend less on food then the goods bought instead will be of approximately the same energy-intensity. However, this work shows that it is important to distinguish between energy and greenhouse emissions; since agriculture leads to large emissions of greenhouse gases of non-fossil origin, there is a benefit here that is not negated through rebound.

Leander (2015) investigates the extent to which the costs of air transport are internalized, and what the significance is in terms of overall demand patterns and environmental damages. As part of the study she estimates the price- and income-elasticity of demand for air travel. There is remarkably little research on this question. As discussed by Leander, many of the studies that do exist rely on time-series data on the aggregate quantity of air travel, average air fares, and aggregate income. This is a highly problematic approach, since price and income are typically correlated with a time trend, i.e. we have multicollinearity. Leander bases her estimation on household expenditure data for different income groups. This allows her to directly estimate income elasticity, without the confounding influence of variations over time in variables other than income. Having found income elasticity, she can then estimate price elasticity as a residual. Leander finds that the income elasticity of demand is around 2, whereas the price elasticity is around -2. Both elasticities are significantly higher than is typically found in the literature; if confirmed in the project this would suggest that the need to manage air travel through price-based instruments is more urgent than has previously been thought.

Planned research. The initial research plan is to repeat the analysis of Leander (2015) on the income- and price-elasticity of demand for air travel, and to apply the results to a deeper analysis of policy options within the air transport sector. One problem with Leander (2015) is that the data we obtained were organized into deciles by *income*, whereas they should have been organized according to *expenditure*. Expenditure gives a better measure of the long-run income of the household than does short-run income; for instance, a student soon to graduate and expecting to earn a high income in the near future may have low current income, but a current expenditure pattern reflecting her high expected income in the future. By rerunning the study using data based on expenditure deciles we expect to obtain better results (in the sense of higher statistical significance) and may well also find even higher demand elasticities. A further improvement will be to analyse the data using more sophisticated econometric methods not appropriate within the scope of a Master's thesis.

Further work is planned to extend to same approach to the study of other sectors, including other forms of transport, and housing, on which data is available from SCB. It would also be very interesting if we could obtain household data from other countries, allowing us to broaden the analysis further. Furthermore, we hope to link the results to the macroeconomic modelling described above, allowing us to build up a better picture of how consumption patterns are determined as a function of incomes, relative prices, and (ideally) country-specific factors.

3.3. Optimal labour supply

The third research objective is to investigate the importance of consumption externalities in determining optimal labour supply, and again to derive policy conclusions.

Prescott (2004) analyses labour supply and tax policy in the G7 countries. How shows that labour supply per capita in the US rose dramatically between the 1970s and the 1990s relative to the other countries: in the '70s it was comparable to European members of the G7, whereas by the '90s it had almost caught up with Japan and was around 50 percent higher than France and Italy. He attributes this change largely to tax policy. Prescott (2004) also shows that—over the same time period—labour productivity converged, i.e. the lead enjoyed by the US diminished; indeed France actually overtook the US, Germany caught up fully, and also Italy, the UK and Japan took major strides forward.

Given the research on consumption externalities cited above (e.g. Aronsson and Johansson-Stenman, 2013, 2014), the question then arises of which countries are moving in an optimal direction, the US or France and Italy? The goal is then to find out to what extent observed differences in labour supply, income distribution, and prices can account for differences in environmental burden between US and Europe. And to the extent that they cannot, what other factors are at play, e.g. sociological and cultural, or geographical? And finally, what are the consequences for economic policy?

This part of the project is the most ambitious and long-term, since it is founded on the understanding of the macroeconomics of consumption patterns built up in the earlier parts of the project, while also including insights from the literature on consumption externalities, such as the papers cited above. Hypotheses we will investigate include the idea that high income inequality leads to high energy demand, if the very rich spend disproportionately on energy-intensive goods. And the idea that high labour supply leads to high energy demand per unit of GDP, since it gives a high GDP per capita even given a relatively low level of input productivity. And high GDP leads to the choice of energy-intensive consumption categories, while low energy productivity leads to high energy consumption across the board.

Finally, a very promising future line of research is to study the effect of past relative consumption in shaping current preferences. If a country, such as the US, has long had higher GDP per capita than its neighbours due to superior technology, what happens if and when the neighbours start to catch up? If the US has a preference not to lose its income advantage, one response would be to raise labour supply and cut provision of public goods. Could this be part of the explanation for the developments of the last 40 years? And if so, does this story contain policy lessons relevant to Europe, and Sweden in particular?

4. Practical relevance

The research project is directly relevant to the goals of the research call, i.e. to provide proposals for effective policy instruments and measures that lead to reduced environmental and health effects, both in Sweden and elsewhere. The main focus of the project is on linking production and consumption to energy and fossil-fuel consumption, and hence to carbon emissions.

The exact significance of the project depends on the results, however we can of course sketch the possible effects of the three parts of the project. Recall that the first objective is to build a macroeconomic, general-equilibrium model of the economy to help us understand historical patterns of primary energy use, and to predict the effects of policy measures. This framework will be based on advanced theoretical modelling, but it will also lead to concrete and easily understood results which help us to understand how different aspects of the economy—including decisions about consumption and production, technological progress, and energy use—are linked, and thus to help us understand the overall effects of specific policy measures. Preliminary results suggest that measures which increase the efficiency of low-energy consumption alternatives should be especially favoured as they should lead to 'reverse-rebound'; as their price falls, consumers switch towards them, and thus away from more energy-intensive alternatives. On the other hand, we should beware of supporting efficiency improvements in energy-intensive consumption categories which are currently only affordable to the richest; reductions in price of such goods may lead to substantial backfire effects.

Very generally, the preliminary results show that it is important to be explicit about labour supply, and that the natural assumption is that if policies do not affect the incentives to supply labour then it should be treated as either fixed or exogenous. If labour supply is fixed then it determines the overall scale of productive effort in the economy, and the key 'currency' to compare consumption goods in climate analysis should be carbon emissions *per unit of labour input* or (allowing the labour inputs embodied in capital) carbon emissions per SEK spent. So if a consumer switches from eating beef to carrots, and beef costs 10 times more than carrots for a day's food intake, then to assess the climate gains we need to look at the re-spend. Fundamentally, beef costs more because more inputs of labour, capital and land are put into producing a day's worth of beef than a day's worth of carrots. So then we must know what the resources freed up by the switch to carrots are used for.

The second objective of the project is to perform microeconomic studies to understand patterns of demand for individual goods, and link the results to the macroeconomic model. So here we aim to produce concrete results showing the likely effects of specific policies, such as policies to raise the cost of air travel, or policies affecting the costs of car transport. Here we will build on existing studies, and use the insights from our own macroeconomic modelling to strengthen the analysis and produce more complete and credible results.

The third research objective is to investigate the importance of consumption externalities in determining optimal labour supply, and again to derive policy conclusions. It is widely believed that the European socioeconomic model — with relatively high taxes and a high degree of provision of services by the state — leads to lower labour supply. This is typically seen as a bad thing, but in the project we will investigate the extent to which this may be a good thing, contributing both to higher welfare due to increased leisure (which is otherwise underconsumed due to the consumption externality), and to higher welfare due to lower polluting emissions and a greater provision of public goods. Depending on the results, and the quality of the analysis, there is a small chance that this research may have a very radical effect on the attitude to taxation in general and economic instruments for environmental protection in particular. In a sense, the hypothesis turns the 'double dividend' argument on its head; there may be a double dividend from environmental taxes because they both reduce labour supply and lead to increased provision of public goods![4]

5. Organization

The research work in the project will be led by Rob Hart at the Swedish University of Agricultural Sciences. Furthermore, one doctoral student will be employed on the project from August 2016 to the end of the project period. Hart will also cooperate with a large external network of researchers — as detailed below — cooperation which may well lead to joint work. However, funding is not sought for these external contacts.

6. External networks

Hart is involved in a range of external networks relevant to the project. Closest to home is the team at the Institute for International Economics Studies led by John Hassler and Per Krusell. As well as visits for seminars and research discussions, Hart attended the IIES conference on Climate and the Economy in September 2012, and the 7th Nordic Summer Symposium in Macroeconomics in August 2013. This cooperation gives Hart access to their world-leading skills in mathematical modelling and data analysis, complementing his ability to capture the key elements of economic systems in a realistic but simple manner.

[4] For an introduction to the double-dividend debate see Bovenberg and de Mooij (1994).

Hart also have good contact with researchers in Norway, strengthened since his co-author Daniel Spiro took up his post at the University of Oslo. Finally, he has excellent contact with a number of European researchers in the field of macroeconomics, technological change, and the environment. Among other things he has over the last few years given invited seminars at the Tinbergen Institute in Amsterdam, the University of Toulouse in France, and Tilburg University in the Netherlands.

A crucial part of the project will involve building up networks within relevant authorities and policy research centres in Sweden, in order to gain input into relevant research questions, and also for support in identifying sources of data and other expertise. I already have very good contacts in several agencies, including the EPA, and hope to improve these through this project.

7. Publication of data

All data used and compiled during the project will be freely available on the internet, except in cases where privacy rules restrict this. We do not expect the latter caveat to apply in practice as—even when we use household data—it will be aggregated into expenditure deciles.

8. Communication

Regarding communication, the primary aim as an academic economist is to publish in widely read international journals, and thus to influence other researchers and policy makers over as broad a spectrum as possible. For results of global relevance the ultimate aim is to publish in very widely read and influential journals such as the *American Economic Review*, or field journals such as the *Journal of Environmental Economics and Management*.

The primary aim as a project-funded researcher is of course to communicate the results to the project stakeholders, including the Swedish EPA, the Swedish environmental policy community, and the general public. I look forward to developing a close working relationship with the EPA. At the start of the project I will establish contact with one of the environmental economists at the EPA; at the moment the plan is that the contact person will be Henrik Scharin. I will meet the contact person at least once a year, hopefully more frequently, to discuss progress on the project and future directions. Furthermore, a final seminar will be held at the EPA, plans for which will be developed together with the contact person. In connection with this seminar I will also deliver a written report.

In addition, the research results are likely to be of broad general interest and therefore should also be published in debating fora within Sweden, such as national newspapers and websites.

9. Activity plan

The activity plan consists of reference group meetings and a plan for production and publication of five scientific papers. A doctoral student will be recruited to work on the project. This student will only have $2\frac{1}{2}$ years within the project; the remainder will be financed from other sources but will largely consist of carrying on work related to the project goals.

Year 1

- Recruitment of doctoral student, appointed July 2016.
- Scientific papers.
  - Rebound, directed technological change, and aggregate demand for energy. *Submitted for publication.*

- At least one meeting with contact person at EPA, participation in 'Forskningsdagen 2016' at the EPA.

Year 2

- Scientific papers.
  - Rebound, directed technological change, and aggregate demand for energy. *Accepted for publication.*
  - Technology policy, preferences, and rebound: A general-equilibrium analysis. *Submitted for publication.*
  - Demand elasticity for air travel, rebound, and climate policy. *Submitted for publication.*
  - Rebound effects with non-Gorman preferences. *Submitted for publication.*
- At least one meeting with contact person at EPA, participation in 'Forskningsdagen 2017' at the EPA.

Year 3

- Scientific papers.
  - Technology policy, preferences, and rebound: A general-equilibrium analysis. *Accepted for publication.*
  - Demand elasticity for air travel, rebound, and climate policy. *Accepted for publication.*
  - Rebound effects with non-Gorman preferences. *Accepted for publication.*
  - Consumption externalities, environmental quality, and optimal labour supply: A comparison of European and US policy. *Submitted for publication.*
- At least one meeting with contact person at EPA, participation in 'Forskningsdagen 2018' at the EPA, and final project seminar at the EPA, including an oral presentation and the delivery of a written report.

10. Budget

The budget is set out in Table 1 below. The total budget for the project is thus 2.834 million SEK spread over three years. Note that we only seek money for salary costs. All other costs, including for instance conference attendance of fees for submission of papers, will be covered from the research group budget.

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		2016	2017	2018	Total
Hart	Months employed	12	12	12	
	% on project	30	30	30	
	Annual salary cost	880	889	898	
	Salary cost on project	264	267	269	800
Doctoral student	Months employed	6	12	12	
	% on project	100	100	100	
	Annual salary cost	445	450	468	
	Salary cost on project	223	450	468	1141
Total salary costs		487	717	738	1941
Total costs (incl. 46% o/h)		711	1046	1077	2834

Table 1: The project budget by calendar year. All numbers in thousand SEK.

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