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A multi-method approach for analysing the potential employment impacts of material efficiency

Simone Cooper[a], Alexandra C.H. Skelton[a], Anne Owen[b], Danielle Densley-Tingley[a], Julian M. Allwood[a,*]

[a] Department of Engineering, University of Cambridge, Cambridge, United Kingdom
[b] School of Earth and Environment, Sustainability Research Institute, University of Leeds, Leeds, United Kingdom

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ABSTRACT

Material efficiency, reducing the amount of new material inputs per given level of service or output, can improve both the resource efficiency of an economy and reduce demand for energy and GHG emissions intensive materials. It requires a change in the way materials, components and final products are used along the supply chain with associated impacts on employment. Domestic policy support for material efficiency can be hindered by concerns that reducing demand for new materials will impact on employment. A multi-method approach for evaluating the employment impacts of material efficiency strategies across different products and regions is presented. It is applied to two case studies that could reduce demand for new steel in the UK: car clubs and re-using steel sections. Industry interviews supplemented by a literature review reveal how sector labour intensity, product prices and sales volumes might change along the mobility and construction supply chains in the short-term as a consequence of introducing these strategies. A static multi-regional input-output model is used to estimate the immediate direct and indirect supply chain employment impacts of increasing the material efficiency of steel use in the UK. The principal finding of this paper, based on industry expectations of feasible rates of deployment, is that the initial, immediate consequences of these actions would not adversely affect employment prospects in the UK. This is partly because car clubs can stimulate demand for new vehicles and deconstructing rather than demolishing buildings is labour intensive, substituting domestic labour for imported steel. These initial findings should motivate further research on the opportunities for material efficiency.

1. Introduction

In 2011, the European Commission (2011) developed a Resource Efficiency Roadmap to enable Member States to shift their economies onto more sustainable growth trajectories while improving competitiveness and creating more employment. To achieve this change, innovation is needed across industries and supply chains to maximise the opportunities from stocks of resources, minimise waste and understand the interactions between different sustainability objectives.

Climate change is one such objective. Current greenhouse gas emissions targets are unlikely to keep temperature increases below 2 °C (Anderson and Bows, 2011). Material efficiency, reducing the amount of new material inputs per given level of service or output, would improve both the resource efficiency of an economy and reduce demand for energy and greenhouse gas (GHG) emissions intensive materials such as steel. DECC (2015) reported that in 2013 steel production accounted for around 20% of domestic industrial GHG emissions in the UK. Eurofer (2014), the European steel manufacturer's association, concludes the introduction of cost effective mitigation technologies would lead to just a 15% improvement in the CO_2 emissions intensity of steel production by 2050 relative to 2010 levels. Therefore in the case of steel, demand-side GHG abatement measures, including material efficiency are both complementary and critical for contributing to the UK's 2050 economy-wide emissions target of reducing domestic greenhouse gas emissions by at least 80% below 1990 levels by 2050 (HMSO, 2008).

Allwood et al. (2012) propose six categories of material efficiency: (1) light-weighting, (2) scrap diversion, (3) yield improvements, (4) reuse without re-melting, (5) life extension and (6) more intense use. All options are preferable to material recycling

* Corresponding author. Tel.: +44 1223338181; fax: +44 1223332643.
E-mail address: jma42@cam.ac.uk (J.M. Allwood).

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in the European Parliament and Council (2008) waste hierarchy. In spite of these potential environmental benefits, material efficiency has received little attention to date (IPCC, 2014).

As discussed in Söderholm and Tilton (2012) there are a multitude of market failures that act against the adoption of material efficiency. In addition, labour taxes distort the incentive to adopt certain material efficient practices (Skelton and Allwood, 2013). This should motivate further investigation into policy interventions to support material efficiency initiatives. However, policymakers can be discouraged from actively addressing these market failures due to concerns that reducing demand for new materials will adversely affect employment. Employment is highlighted in the HM Treasury's Green Book on appraisal and evaluation as both a motivation for, and an important evaluation indicator of, government intervention in the UK. This paper presents a novel multi-method approach for investigating the immediate direct and indirect supply chain employment impacts of increasing the material efficiency of steel use in the UK. It includes surveys, literature reviews and multi-regional input–output (MRIO) modelling. This approach is replicable for other categories of material efficiency and can be applied to any geographic region covered by an MRIO model.

2. Motivation for material efficiency and modelling approaches for measuring employment impacts

Two case studies were selected in the UK automotive and construction sectors as these are the largest users of steel globally, accounting for over two thirds of demand in 2007 (Cullen et al., 2012). For the construction sector, the material efficiency category of 'reuse without re-melting' was chosen, using the example of re-using steel sections. In the automotive sector, the category of 'more intense use' was investigated using the example of car clubs. Two literature reviews were conducted. First to understand the feasibility and possible motivation for introducing these two strategies in the UK and second to ascertain different modelling approaches and estimates of the employment impacts associated with their introduction.

2.1. Feasibility and motivation for increasing re-used steel sections in UK construction

There are several options for re-using steel in the construction sector without recycling. Individual elements (e.g. a steel sections), components (e.g. trusses) and whole steel structures could theoretically be reused in new construction projects. Reuse can occur either in-situ or in a new location, and is more likely if a building has been designed for deconstruction and reuse early in the project development process (Densley-Tingley and Davison, 2011). The focus of this research is on the reuse of steel sections. Statistics from the ISSB reveal that between 2003 and 2008 around half of the tonnage of steel purchased by the UK construction industry were steel sections. Currently only 7% of steel salvaged from demolition sites in the UK is reused (Sansom and Avery, 2014). The remaining 93% is recycled by upstream steel manufacturers. Although less emissions intensive than making virgin steel, recycling scrap still generates an average of 0.33 t CO_2/t steel (Milford et al., 2013). Ley et al. (2002) conducted a MFA of steel use in the UK construction sector and estimated that in 2011 approximately 250 kt of scrap steel sections could have been salvaged from demolition sites. If all sections were re-used rather than recycled, this would have avoided approximately 83 kt of CO_2 emissions per annum. Reusing steel sections is technically feasible across a number of geographies and building types, as demonstrated by case studies for industrial (Pongiglione and Calderini, 2014) residential, (Chance, 2009) and commercial buildings (Gorgolewski, 2008). Using evidence from case studies in Canada, Gorgolewski (2008) concludes that reuse could also be facilitated by ensuring a sufficient local stock of reuseable steel sections to reduce project delays; attaining early buy-in from designers; and improving the traceability of reuseable steel to overcome any potential concerns around quality for downstream users.

2.2. Feasibility and motivation for increasing the number of car club members

UK citizens are making fewer and shorter trips by car (DFT, 2014a) but the total number of cars registered to UK drivers is rising (SMMT, 2015). On average a car contains around 900 kg of steel, generating approximately 1.8 t of CO_2 by steel manufacturers upstream (World Steel, 2014). Cars are increasingly under-utilised but there is still a clear demand from drivers to have access to one. Car sharing offers an opportunity to increase drivers' access to cars and increase the intensity of car use. Drivers can either share car journeys or vehicles. The latter of which can occur through peer-to-peer sharing, where individuals retain ownership of their cars and loan them temporarily to others or via car clubs, where vehicles are owned by the car club operator. Around 0.01% of UK drivers currently belong to a car club (Steer Davis Gleave, 2015; DFT, 2014b). The focus of this research is on increasing the number of car sharers via car clubs in the UK. Membership to a car club can lead to a driver delaying or deterring a private car purchase, thus reducing the demand for cars and for emissions intensive inputs including steel. However, Millard-ball et al. (2005) highlight the challenge of accurately measuring private vehicle displacement rates, particularly if interviewees are asked to speculate on avoided future purchases. Recognising this challenge and the associated uncertainty, Carplus, a not-for-profit environmental transport NGO, surveyed UK car club members (Steer Davis Gleave, 2015) and estimated that, in 2014/2015, between 3.5 and 8.6 private new and second-hand vehicles were removed from the road for every car club vehicle. Sharing vehicles has many additional potential environmental and social benefits including reduced congestion and competition for parking spaces, improved local air quality and increased mobility access. These potential benefits have prompted local and central government to support the expansion of car club membership across the UK (DFT, 2014c).

If introduced at a large scale, these two material efficiency strategies would change the supply chain for delivering personal mobility and construction projects in the UK

2.3. Modelling approaches to estimate the employment impacts of material efficiency

Four categories of methodological approaches for assessing the employment impacts of emissions mitigation are proposed in Mirasgedis et al. (2014). These are: (i) indices and multipliers from specific case studies, (ii) input–output (IO) analysis (iii) top down modelling approaches such as econometric or computable general equilibrium models and (iv) hybrid approaches. A static MRIO model was used in this study as provides a transparent method that can offer an estimate of the likely scale and sectoral location of the immediate, direct and indirect employment impacts arising from changes in the structure of an economy due to the introduction of material efficiency initiatives. Static MRIO models provide a snapshot of an economy at a particular point in time. When the production structure within these models is modified, as is the case in this study, the results reveal net changes in output and employment relative to the historical structure of the economy. These changes include direct employment impacts from a change in direct sector purchases (e.g. less new steel bought by the construction

Table 1
Literature review of studies estimating the employment impacts of car sharing and reuse of steel in construction.

Study	Geographic area	Strategies considered	Methods		Conclusions
Coelho and De Brito (2011)	Lisbon, Portugal	Deconstruction of buildings (a precursor for material reuse)	Case studies (i)	Direct	Labour costs for selective demolition (deconstruction) are 6 times higher than for standard demolition for several town houses. Requires 14 times more unskilled labour, 2.5 times more labour from equipment operators and 8.8 times more labour from supervisors
Dantata et al. (2005)	Massachusetts, USA	Deconstruction of buildings (a precursor for material reuse)	Case studies (i)	Direct	Deconstruction labour costs are double that of demolition. Additional labour requirements for unskilled workers, equipment operators and supervisors
da Rocha and Sattler (2009)	Porto Alegro, Brazil	Deconstruction of buildings (a precursor for material reuse)	Case studies (i)	Direct	Potential increase in labour requirements and net reduction in project costs, as labour costs are relatively cheaper than machinery and material costs
Walz (2011)	Germany	Share of German car club users increases from 2.5–10% and 70% of new users no longer own a car	Dynamic input output model (ii)	Direct & indirect supply chain	Car sharing increases net domestic employment by around 18,000 jobs. Approximately 30,000 new jobs expected in German service sectors, fall of 12,000 jobs expected in sectors related to investment goods and basic materials
de Bruyn et al. (2012)	Global	Shared ownership of hybrid and electric vehicles	Literature review of case studies (i)	n/a	Hybrid and electric vehicles are more expensive and encourage shared ownership. The employment impacts are inconclusive and dependent on the relative impacts of higher vehicle purchase price and lower operating costs

industry) and indirect impacts that affect employment higher up the supply chain (e.g. fewer jobs to mine coal which would then be sold to the steel industry to make products used by the construction industry). There may also be employment impacts resulting from a change in household disposable income, (e.g. if car sharing reduces the costs of mobility, households will spend money on other goods and services and create jobs in those sectors). These are referred to as induced impacts and are one aspect of a potential rebound effect. Another aspect of the rebound effect which is not captured in a static MRIO framework is the impact of a change in product prices on consumption choices which could lead to both income and substitution effects. Sorrell (2007) reviewed over 500 studies on the evidence for rebound effects for energy efficiency initiatives and concluded that rebound effects vary widely between different technologies, sectors and income groups that cannot be quantified with much confidence. So although other top down modelling approaches can offer estimates of these rebound effects they require additional assumptions that create further uncertainties.

A number of other studies have used a static MRIO model to compare different states of the economy including Skelton and Allwood (2013), Bordigoni et al. (2012) and Morgenstern et al. (2004). However the lack of feedback mechanisms in the model means the results should only be interpreted as the immediate, short term consequences of introducing material efficiency initiatives. In Section 4.2 we also discuss the likelihood of these strategies leading to a change in product prices, which is excluded from the modelling analysis. Guidance is offered on where to focus future research on price responses and feedback mechanisms, which could influence the employment impacts of these material efficiency measures.

Many studies have assessed the employment impacts of environmental policies and technologies including energy efficiency initiatives and deployment of renewable energy technologies (see reviews in Mirasgedis et al., 2014; Wei et al., 2010). However only a handful of equivalent studies were found on material efficiency. Table 1 summarises the current research insights for the two chosen initiatives.

Table 1 shows that there is a precedent for this type of analysis. However, no studies currently exist for the UK that assess the immediate direct and indirect supply chain employment impacts of reusing steel sections or increasing the number of car club members.

3. Methodology for estimating supply chain employment impacts associated with material efficiency case studies

The methodology used in this paper can be explained in four stages. First, an IO model was used to calculate historical construction and motor vehicle supply chain employment trends for the years 1997–2011 (Section 3.1). Second, sectors in the input–output model were disaggregated to specific subsectors and sub-products of interest (Section 3.2). Third, interviews were conducted with industrial stakeholders to ascertain how the supply chains for construction and personal mobility would change for each material efficiency strategy (Section 3.3). Finally, the proposed changes to supply chains were characterised as changes to sales volumes, product prices and labour intensities in the IO table for the year 2011. The net changes in domestic and international direct and indirect supply chain employment were estimated (Section 3.4).

3.1. Model description

This paper adopted the established methodology of estimating direct and indirect supply chain impacts using sector employment intensity metrics in an IO framework. These are referred to in the IO literature as 'Type I' multipliers (Miller and Blair, 2009). The model was developed at the University of Leeds described in Scott et al. (2013). In the model, the global economy is split into two-regions, the 'United Kingdom' (UK) and 'Rest of World' (RoW). The model was chosen because of the accuracy of the UK data, taken directly from the Office of National Statistics (ONS) for the years 1997–2011. RoW data was sourced from the Eora MRIO database described in Lenzen et al. (2013) and converted to pounds sterling. The model splits the global economy into 106 sectors and products, aligning

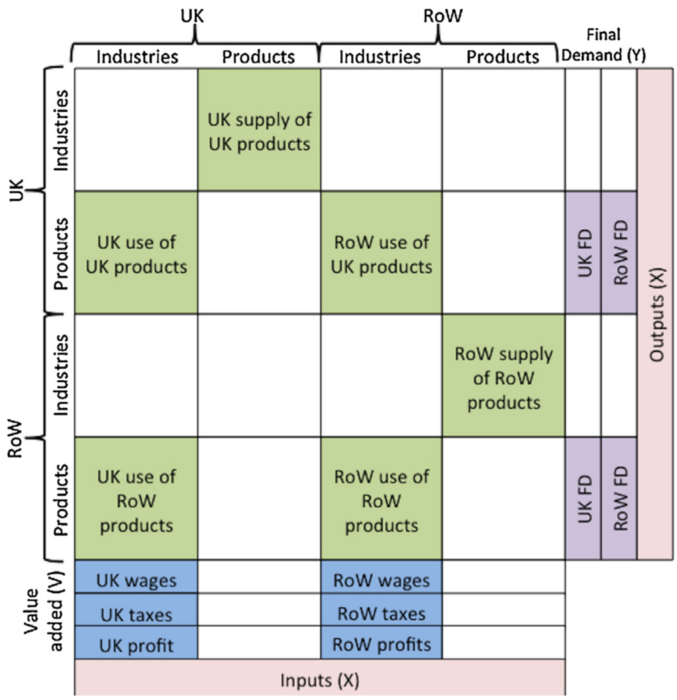

Fig. 1. Structure of Leeds University MRIO model for a single year (without employment extension).

with the UK's 2-digit standard industrial classification (SIC) code. The layout of the model for a single year is shown in Fig. 1.

Coloured squares are 106 × 106 matrices containing non-zero values; non-coloured squares are 106 × 106 matrices containing zeros. In matrix notation, the supply and use table ($\boldsymbol{Z}$) can be written as:

$$\boldsymbol{Z} = \begin{pmatrix} 0 & \boldsymbol{S}^{\mathbf{uk}} & 0 & 0 \\ \boldsymbol{U}^{\mathbf{uk,uk}} & 0 & \boldsymbol{U}^{\mathbf{row,uk}} & 0 \\ 0 & 0 & 0 & \boldsymbol{S}^{\mathbf{row}} \\ \boldsymbol{U}^{\mathbf{uk,row}} & 0 & \boldsymbol{U}^{\mathbf{row,row}} & 0 \end{pmatrix} \tag{1}$$

In the general notation, $\boldsymbol{U}^{sr}$ is a matrix of inputs into region s, from region r. Element u_{ij}^{sr} is the amount spent by each industry i in region s on product j from region r, also referred to as 'intermediate demand'. Similarly in the supply matrix $\boldsymbol{S}^{s}$, element S_{ij}^{s} details how much of product j is made by sector i in region s. The rows of value added (V) in Fig. 1 shows the amount each sector spends on non-physical inputs i.e. wages, taxation and profit. In matrix notation, this is written as:

$$\boldsymbol{V}' = \begin{pmatrix} \boldsymbol{V}^{\mathbf{uk}} & 0 & \boldsymbol{V}^{\mathbf{row}} & 0 \end{pmatrix} \tag{2}$$

Each element, v_i^s shows how much is spent by sector i on non-physical inputs in region s. In Fig. 1, the column Y shows final demand. This is how much final consumers in each region spend on each product in each region. In matrix notation, this is written as:

$$\boldsymbol{Y}^{\mathrm{uk}} = \begin{pmatrix} 0 \\ \boldsymbol{Y}^{\boldsymbol{uk,uk}} \\ 0 \\ \boldsymbol{Y}^{\boldsymbol{uk,row}} \end{pmatrix}, \quad \boldsymbol{Y}^{\boldsymbol{row}} = \begin{pmatrix} 0 \\ \boldsymbol{Y}^{\boldsymbol{row,uk}} \\ 0 \\ \boldsymbol{Y}^{\boldsymbol{row,row}} \end{pmatrix} \tag{3}$$

The general notation for element y_j^{sr} shows how much is spent on product j made in region r by final consumers in region s. A condition of the model is that the sum totals of all inputs (columns) are equal to the sum of all outputs (rows). Each element is divided by the total sum of the column $\left(X_j^s\right)$. This generates the direct requirements or "A" matrix containing elements $a_{ij}^s = u_{ij}^s / X_j^s$. $\boldsymbol{A}$ was used to calculate the Leontief inverse using the equation:

$$\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1} \tag{4}$$

$\boldsymbol{I}$ is an identity matrix the same dimensions as $\boldsymbol{A}$. The Leontief matrix shows the *total* input requirements to deliver a unit of output, i.e. direct and all indirect inputs along the entire supply chain. An additional vector of labour intensity $\boldsymbol{F}$ was included in the model and transposed ($\boldsymbol{F}'$).

$$\boldsymbol{F}' = \begin{pmatrix} \boldsymbol{F}^{\mathbf{uk}} & 0 & \boldsymbol{F}^{\mathbf{RoW}} & 0 \end{pmatrix}$$

It is defined by elements $f_j^s = m_j^s / X_j^s$ where m_j^s is the annual number of full time workers in sector j in region s, and X_j^s is the total value of output in sector j in region s. The matrix of direct and indirect employment to meet UK demand for products in a single year was calculated by the formula:

$$\boldsymbol{M} = \hat{\boldsymbol{F}} * \boldsymbol{L} * \hat{\boldsymbol{Y}}^{\mathbf{uk}} \tag{5}$$

A $\hat{}$ denotes a square matrix with the vector values along the diagonal and zeros elsewhere. Formula (5) was used to calculate the UK and RoW employment associated with meeting UK demand for products for all years between 1997 and 2011. Employment associated with individual supply chains are captured by columns in the $\boldsymbol{M}$ matrix.

3.2. Product and sector disaggregation

Fig. 1 shows inter-sectoral monetary flows of payments between 106 sectors for 106 products. However, only certain sub-sectors and sub-products would be impacted by each material efficiency initiative. Further disaggregation in the model was necessary to avoid over-estimating the change in monetary flows. For direct purchases between sectors and by final customers, the proportion of output attributable to a specific subsector was approximated using total sub-sector turnover as a proportion of total sector turnover, taken from the Annual Business Survey (ABS) (ONS, 2014a) for the year 2011. Indirect purchases between sectors were estimated using the value of steel sales to a particular sector as a proportion of total steel sales (ONS, 2014b). No equivalent information was available for international sub-sector turnover and sales so UK proportions were applied.

The reuse case study focuses solely on steel sections. Steel products are priced differently depending on the method of production and processing. To estimate the price of steel sections in the model, domestic and international steel mass flow data was taken from ISSB (2008) and combined with relative historical steel product prices for the year 2011 (*MEPS, Platts, ISSB*). Fig. 2 shows the estimated proportion of mass flows and direct and indirect expenditure attributable to different steel products bought by the construction sector in 2011.

3.3. Interviews and literature review

17 semi-structured interviews were conducted with UK mobility and construction sector experts to ascertain how these two material efficiency strategies would be implemented in the short-term. Interviewees were asked to consider how costs, sales volumes and labour requirements might change across different sectors in the supply chain. Interview questions used to prompt a discussion are detailed in Table 2 and a list of interviewees and their relevant experience is included in the supplementary information. Only a few respondents in the reuse case study had direct experience of

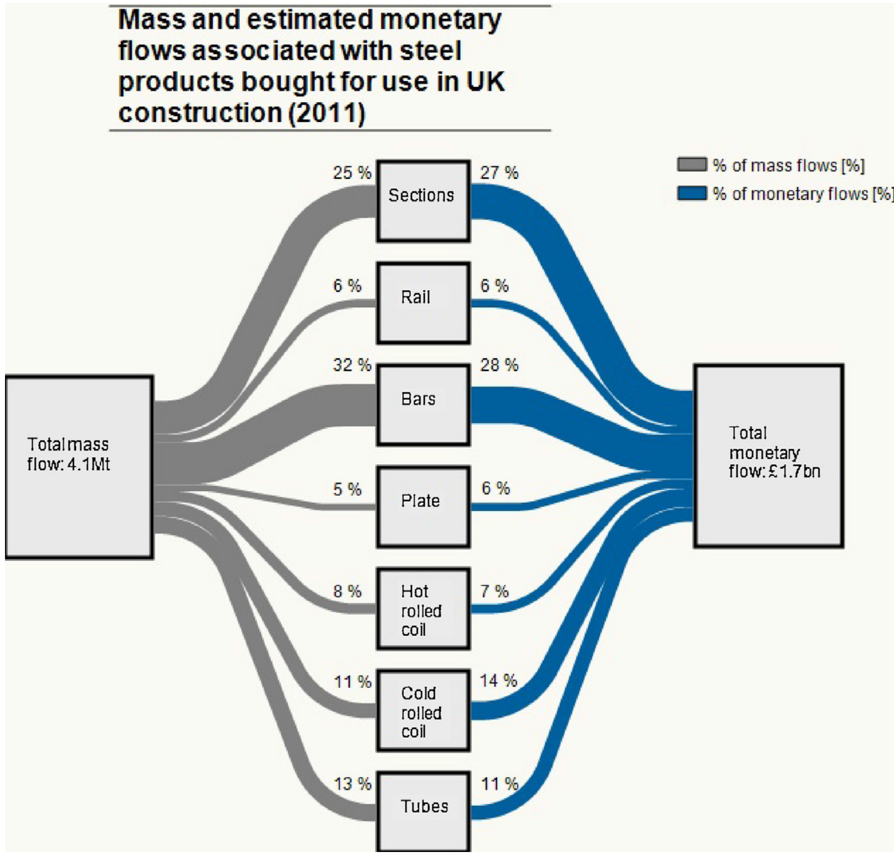

Fig. 2. Sankey diagram converting mass flows of steel products bought by the construction sector in 2011 into equivalent monetary flows.

re-using steel so questions were more hypothetical. Conversely, there are currently eight commercial car club operators in the UK. Car club interview questions focused on understanding different costs and labour requirements per member and vehicle.

The collated interview responses are summarised in Table 3. The table includes an explanation of why monetary flows between sectors would change as a consequence of introducing each material efficiency initiative and provides an estimate of the maximum size of monetary flows that would be affected, using the methods described in Section 2.3.

For each supply chain change listed in Table 3, an additional review of academic, industry and government issued literature was conducted to corroborate and find quantitative estimates of the changes proposed. If no further evidence was found in the literature, the change was omitted from the modelling exercise. In the re-use case study, it was challenging to find additional information on search, haulage, cleaning, testing and storage costs so these were omitted from the modelling work. The modelling therefore only includes a partial assessment of the immediate changes in direct and indirect supply chain employment in the re-use case study.

In the car club case study, a low case of 100,000 members was assumed and a high case of 1 million members. The upper case is a credible assumption as in London alone there is an ambitious strategy outlined in Transport for London (TFL) (2015) for 1 million car club users by 2025.

3.4. Modelling assumptions

The supply chain changes detailed in Table 3 were used to guide the modification of sector labour intensity, sales volumes and product prices. Returning to the model description in Section 3.1, inter-sector monetary flows (intermediate demand) and payment

Table 2
List of questions that formed the basis of the semi-structured interviews conducted with representatives from the UK construction and automotive supply chain.

Case study: reusing steel sections	Case study: car clubs
Interview questions	*Interview questions*
• Are you involved with material purchasing/sourcing decisions? How is this done? E.g. on a project-by-project basis or is there a coordinated company approach?	• Approximately how many individuals work at your company/across all UK car club companies? What types of roles? Which roles are impacted by the number of car club members?
• How would you source reused steel sections for a project?	• How many vehicles are bought on average per car club member? How often are car club vehicles replaced?
• Do you think a project with reused steel will require more or less labour? More or less material inputs? New capital equipment? Why?	• How are car club vehicles manufactured? Does this differ at all from private vehicle manufacturing?
• Would project costs be impacted? Why?	• How are car club vehicles purchased?
• Would the use of reused steel affect consumer demand for construction projects?	• Who is responsible for vehicle maintenance? How frequently are car club vehicles checked?
• What percentage of the yearly sectional steel stocks arising from demolition do you think could be suitable for structural reuse by 2020?	• How are car club vehicles insured? How are insurance premiums calculated?
	• What is the potential size of the UK car sharing market in 2020?

Table 3
Summary of interview responses that show which inter-sector and inter-stakeholder monetary flows are anticipated to change with the introduction of each material efficiency strategy and what the maximum scale of change would be for the year 2011.

Case study (possible rate of implementation)	Customer	Sector supplying goods and services for purchase (SIC code)	Region	Value of monetary flows in IO table for 2011 (£m)	Sub-sector impacted by material efficiency initiative (SIC code)	Expected impact of material efficiency initiative (based on interview evidence)	Sub-sector turnover/total sector turnover (ONS, 2014a)	Max value of inter-sector monetary flows impacted by material efficiency initiative (£m)	Inclusion in modelling?
Reuse steel sections (assumed to be possible for 10% of sections extracted from deconstruction sites)	Construction sector	Construction (43)	UK	**46,111**	Development of building projects (41.1)	Additional search costs would be incurred to source reused steel.	9%	**3991**	N
					Demolition (43.11)	More reused steel would be sold by the demolition subsector of the construction industry to the rest of the construction industry for use in future building projects	0.20%	**109**	Y
		Land transport services (49)	UK	**1036**	Freight transport by road (49.1)	Reused steel sections from deconstruction sites would need to be transported to steel fabricators	46%	**481**	N
		Fabricated metal products (25)	UK	**4258**	Fabrication of metal structures (25.11)	Reused steel sections from deconstruction sites would be cleaned so condition is equivalent to new steel	20%	**844**	N
		Architectural and engineering services (71)	UK	**5258**	Technical testing and analysis (71.1)	Reused steel would need to be tested and certified to confirm its material properties for reuse	9%	**463**	N
		Warehousing and support services for transportation (52)	UK	**75**	Warehousing and storage (52.1)	Once cleaned and certified, reused steel sections from deconstruction sites would need to be stored before being sold for future construction projects	25%	**19**	N
		Manufacture of basic metals (24)	UK	**34**	Manufacture of steel products (24.1-24.3)	Fewer new steel sections would be bought directly by the construction industry	100%	**34**	Y
			RoW	**147**			100%	**147**	Y
Total				**56,919**	**Total**			**6088**	
Car sharing (low membership case of 300,000 and high membership case of 1000,000	Rental and leasing services sector	Manufacture of motor vehicles, trailers and semi-trailers (29)	UK	**2**	Manufacture of motor vehicles (29.1)	More motor vehicles would be bought by rental and leasing companies to meet the growing mobility needs of car club members	24%	**0.4**	Y
			ROW	**498**			24%	**121**	Y
		Wholesale and retail trade and repair services of motor vehicles and motorcycles (45)	UK	**1238**	Sale of cars and light motor vehicles (45.11)	More motor vehicles would be bought by rental and leasing companies to meet the growing mobility needs of car club members	69%	**851**	Y

Table 3 (*Continued*)

Case study (possible rate of implementation)	Customer	Sector supplying goods and services for purchase (SIC code)	Region	Value of monetary flows in IO table for 2011 (£m)	Sub-sector impacted by material efficiency initiative (SIC code)	Expected impact of material efficiency initiative (based on interview evidence)	Sub-sector turnover/total sector turnover (ONS, 2014a)	Max value of inter-sector monetary flows impacted by material efficiency initiative (£m)	Inclusion in modelling?
					Maintenance and repair of motor vehicles (45.2)	More motor vehicles in the rental and leasing fleet would result in higher expenditure on motor vehicle repair and maintenance	15%	**190**	Y
			ROW	**4**	Sale of cars and light motor vehicles (45.11)	More motor vehicles would be bought by rental and leasing companies to meet the growing mobility needs of car club members	69% (E)	**3**	Y
		Insurance and re-insurance (65)	UK	**166**	Non-life insurance (65.12)	More motor vehicles in the rental and leasing fleet would result in higher expenditure on motor vehicle insurance	30%	**50**	Y
	Households	Rental and leasing activities (77)	UK	**5456**	Rental and leasing of motor vehicles (77.1)	Household expenditure on motor vehicle rental would increase to reflect an increase in car club membership	47%	**2564**	Y
		Manufacture of motor vehicles, trailers and semi-trailers (29)	UK	**5817**	Manufacture of motor vehicles (29.1)	Household expenditure on new motor vehicles would fall if car club membership defers or delays private motor vehicle purchases	24%	**1418**	Y
			ROW	**10,770**			24% (E)	**2626**	Y
		Wholesale and retail trade and repair services of motor vehicles and motorcycles (45)	UK	**20,799**	Sale of cars and light motor vehicles (45.11)	Household expenditure on second-hand motor vehicles would fall as car club membership defers or delays private vehicle purchases	69%	**14,293**	Y
					Maintenance and repair of motor vehicles (45.2)	Household expenditure on maintenance and repair of motor vehicles falls if fewer privately vehicles are owned	15%	**3189**	Y
			ROW	**177**	Sale of cars and light motor vehicles (45.11)	Household expenditure on new motor vehicles would fall if car club membership defers or delays private vehicle purchases	69% (E)	**122**	Y
		Insurance and re-insurance (65)	UK	**48,459**	Non-life insurance (65.12)	Household expenditure on private motor vehicle insurance would fall if fewer privately vehicles are owned	30%	**14,771**	Y
Total				**93,386**	**Total**			**40,198**	

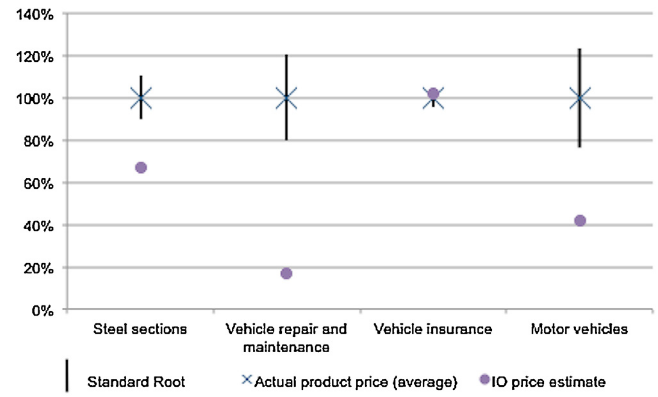

Fig. 3. Estimated product prices used in the MRIO model shown as a percentage of actual historical product prices and the standard root.

by customers for finished goods and services (final demand) can be thought of as:

$$u_{ij}^{sr} = Q_{ij} * P_j \qquad y_j^{sr} = Q_{ij} * P_j \tag{6}$$

To recall, u_{ij}^{sr} is intermediate demand and shows the amount spent by each industry i in region s on product j from region r and y_j^{sr} shows how much is spent on product j made in region r by customers as final demand in region s. This is equivalent to the quantity of product j purchased from sector i in region r (Q_{ij}) multiplied by the price per unit of product j (P_j). It is assumed that products are priced the same across regions. The interviews and literature review provided estimates of current product sales volumes and product prices and how these might change between certain sectors following the introduction of the material efficiency initiative. This enabled new estimates of intermediate and final demand that were calculated using the equations:

$$u_{ij}^{sr(\mathrm{new})} = Q_{ij}^{(\mathrm{new})} * P_j^{(\mathrm{new})} \qquad y_j^{sr(\mathrm{new})} = Q_{ij}^{(\mathrm{new})} * P_j^{(\mathrm{new})} \tag{7}$$

Proposed changes to product sales volumes and prices are detailed in Table 4.

The product prices in Table 4 were estimated from mass flows and monetary flows. These were compared to actual historical price data for the year 2011. Fig. 3 shows the MRIO price estimate as a proportion of actual product prices. Aside from vehicle insurance, most product prices in the model were underestimates.

There may be many reasons for this. First, sub-sector sales to other sectors were apportioned using total sub-sector turnover as a proportion of total sector turnover. This proportion was assumed to be constant across all purchasing sectors. Second, it was challenging to accurately identify which sectors were supplying what sub-products, particularly if these were priced differently across sectors. Third only a limited number of sources were available to use to convert mass flows into equivalent monetary flows in the model. Data from the years 2004–2015 were used. In spite of these potential uncertainties, the estimates used to amend sales volumes, product prices and labour intensity were based on best available information and could be amended easily if further information became available.

The new monetary flows between sectors detailed in Table 4 were changed in the MRIO table for the year 2011. Total sector spend was held constant by modifying the vector of value added in both case studies. For example any money saved on material expenditure was attributed to profits. In the reuse case study, total spend by final customers fell by around £20m in the low case and increased by £330m in the high case. These changes in total spend would lead to very small changes in induced employment and were therefore omitted from the analysis.

Eqs. (1)–(5) in Section 3.1 were then used to calculate the new direct and indirect employment to meet UK demand for products following the introduction of more car club members $\left(\boldsymbol{M}^{\mathbf{car\ club}}\right)$ and reuse of steel sections in UK construction $\left(\boldsymbol{M}^{\mathbf{reuse}}\right)$. Matrices showing the net change ($\boldsymbol{N}$) in labour requirements as a consequence of these two strategies were calculated by:

$$\boldsymbol{N}^{\mathbf{reuse}} = \boldsymbol{M}^{\mathbf{reuse}} - \boldsymbol{M}$$
$$\boldsymbol{N}^{\mathbf{car\ club}} = \boldsymbol{M}^{\mathbf{car\ club}} - \boldsymbol{M}$$

4. Estimates of supply chain employment impacts of material efficiency case studies

This section presents the results of the multi-method approach described in Section 3. Section 4.1 shows historical supply chain employment for the UK construction and UK motor vehicle manufacturing sectors. Section 4.2 shows the net change in supply chain labour requirements for each material efficiency initiative.

4.1. Historical supply chain employment trends

Fig. 4a and b shows direct and indirect supply chain employment to meet UK final demand (FD) for construction and motor vehicle manufacturing. Fig. 4c shows total UK employment in the motor vehicle manufacturing supply chain to meet UK and export demand for vehicles. These historical changes are useful for evaluating the relative size of change in employment for the two material efficiency initiatives.

Fig. 4a shows UK final demand for construction increased at a constant rate of around 8% per annum between 1997 and 2011 except during the 2008–2010 recession. Approximately 70% of supply chain employment for construction is located in the UK. The division of supply chain employment between the UK and RoW remained constant from 1997 to 2004. From 2004 onwards, higher final demand created relatively more jobs abroad. Further analysis of the data shows RoW employment increased most in wood, glass, rubber, machinery and equipment manufacturing sectors.

Domestic suppliers met around 99% of all UK final demand for construction. Conversely, Fig. 4b shows that in 2011, UK motor vehicle manufacturers met only 25% of the value of UK final demand for personal vehicles, down from 50% in 1997. Instead, UK manufacturers focused more on export markets, as is shown by the rise in ROW final demand for UK motor vehicles in Fig. 4c. Although the total value of UK and ROW final demand for UK motor vehicles was 50% higher in 2011 than 1997, total UK supply chain employment fell by around 100,000 jobs. This was probably due to increasing automation in the motor vehicle industry. Given the high reliance on motor vehicle imports in the UK, changes to UK final demand for vehicles, for example through increased car club membership, is unlikely to have a large impact on UK motor vehicle manufacturing employment. However, there will probably be impacts on sectors that provide complementary products and services associated with personal mobility.

4.2. IO modelling estimates of potential supply chain employment impacts

The main results of this paper are presented in Fig. 5a–c. Potential changes in employment are shown as the net changes in indirect and direct supply chain labour requirements for full time workers. Only three supply chains incurred non-negligible (>1000 full time employees) changes in labour requirements.

Table 4
List of proposed changes to inter-sectoral and inter-stakeholder sales volumes and product prices to reflect the introduction of each material efficiency strategy. Inclusion of the original monetary flows and revised monetary flows in the MRIO model.

Case study	Product/service	Sector/sub-sector supplier	Customer	Original physical flows		Original monetary flows and price per unit of product			New physical flows			New monetary flows and price per unit of product			
				Physical sales volume per annum in UK (year)	Source	Monetary sales volume in 2011 IO table (£m)	Estimated price per physical unit	Method of calculation (source)	New physical sales volume		Method of calculation (source)	New price per unit	Method of calculation (source)	New monetary sales volume in IO Table 2011 (£m)	
									Low	High				Low	High
Reuse steel sections in construction	Steel sections	Basic iron and steel	Construction sector	129 kt (2008)	ISSB (2008)	58	£450/t	See Fig. 2	126 kt	126 kt	Assumption that a total of 25 kt of new steel is replaced by reused steel sections	£450/t	n/a	57	5757
			Fabricated metals sector	901		406	£450/t	See Fig. 2	879 kt	879 kt			n/a	396	396
		Demolition/deconstruction	Construction sector	0	Industry interviews	0	0	n/a	25 kt	25 kt	Assumption that 25 kt (10%) of steel sections extracted from demolition sites in the UK in 2011 are reused (industry interviews, Ley et al., 2002)	£225/t	The price reflects the additional deconstruction costs (Geyer and Jackson, 2004) and the opportunity costs of selling the steel sections for scrap.	1	1
			Fabricated metals sector	0	Industry interviews	0	0	n/a						5	5
	Demolition/deconstruction services	Demolition/deconstruction	Construction sector	n/a	n/a	109	n/a	n/a	250 kt	250 kt	Number of steel sections extracted from demolition sites in 2011 (Ley et al., 2002)	£135/t	The price reflects the additional costs of deconstruction compared to demolition (Geyer and Jackson, 2004)	143	143
Car clubs	Car club membership	Rental and leasing	Households	185,000 members (2015)	Steer Davis Gleave (2015)	305	£350/member	Calculated by combining the average hourly price of hiring a car club vehicle in the UK including joining fee (DriveNow, Citycar club, Zipcar, Co-wheels) with the average hours of car club usage per annum (Steer Davis Gleave, 2015)	300,000 members	1,000,000 members	Estimates of future membership levels by 2020 (industry interviews)	£350/member per annum	n/a	345	590
	Motor vehicles	Manufacture of motor vehicles	Households	2 mill new private vehicle registrations (2011)	SMMT (2012)	6,500	£10,050/vehicle	Total expenditure in IO table divided by the number of new private vehicle registrations	1.99 mill new private vehicle registrations	1.94 mill new private vehicle registrations	Calculated by combining estimates of future membership levels with private vehicle displacement rates (Steer Davis Gleave, 2015). Recognising that a proportion of displaced private purchases will be second-hand vehicles (University of Buckingham, 2013)	£10,050/vehicle	As before	6,499	6,317

Table 4 (*Continued*)

Case study	Product/service	Sector/sub-sector supplier	Customer	Original physical flows		Original monetary flows and price per unit of product			New physical flows			New monetary flows and price per unit of product			
				Physical sales volume per annum in UK (year)	Source	Monetary sales volume in 2011 IO table (£m)	Estimated price per physical unit	Method of calculation (source)	New physical sales volume		Method of calculation (source)	New price per unit	Method of calculation (source)	New monetary sales volume in IO Table 2011 (£m)	
									Low	High				Low	High
		Sales of cars and light motor vehicles	Households			13,600								13,597	13,217
	Motor vehicle insurance	Insurance	Households	31.4 mill cars registered cars in the UK in 2011	SMMT (2012)	18,840	£600/vehicle	Only a proportion of household spend is assumed to be on car insurance (ONS, 2012a) as the MRIO model includes other forms of life and non-life insurance (ONS, 2014a). It is assumed that all registered vehicles on the road are insured.	31.39 mill privately-owned cars on the road	31.34 mill privately-owned cars on the road	Membership to a car club leads to displacement of private vehicle ownership	£600/vehicle	As before	18,839	18,806
	Vehicle repair	Maintenance and repair of motor vehicles	Households			3,120	£99/car	A proportion of annual household expenditure on vehicles is on vehicle maintenance (ONS, 2014a). It is assumed that all registered vehicles undergo the same amount of maintenance at the same price.				£99/vehicle	As before	3,108	3,103
	Motor vehicles	Manufacture of motor vehicles	Rental and leasing sector	2,850 registered car club vehicles in the UK (2015)	Steer Davis Gleave (2015)	3	£10,050/vehicle	It is assumed that the price of a car club vehicle is the same as a vehicle purchased by a UK household	4,615 car club vehicles	15,385 car club vehicles	Calculated by combining estimates of future levels of car club membership by 2020 (industry interviews), with estimates of vehicles per car club member (Steer Davis Gleave, 2015)	£10,050/vehicle	As before	4	17
		Sales of cars and light motor vehicles	Rental and leasing sector			25								41	138
	Motor vehicle insurance	Insurance	Rental and leasing sector			2	£600/vehicle	It is assumed that the price of vehicle insurance for a car club vehicle is the same as the insurance price per vehicle paid by UK households				£600/vehicle	As before	3	9
	Vehicle repair	Maintenance and repair of motor vehicles	Rental and leasing sector			0.3	£99/vehicle	It is assumed that the price of vehicle maintenance for a car club vehicle is the same as the maintenance price per vehicle paid by UK households				£99/vehicle	As before	0.5	2

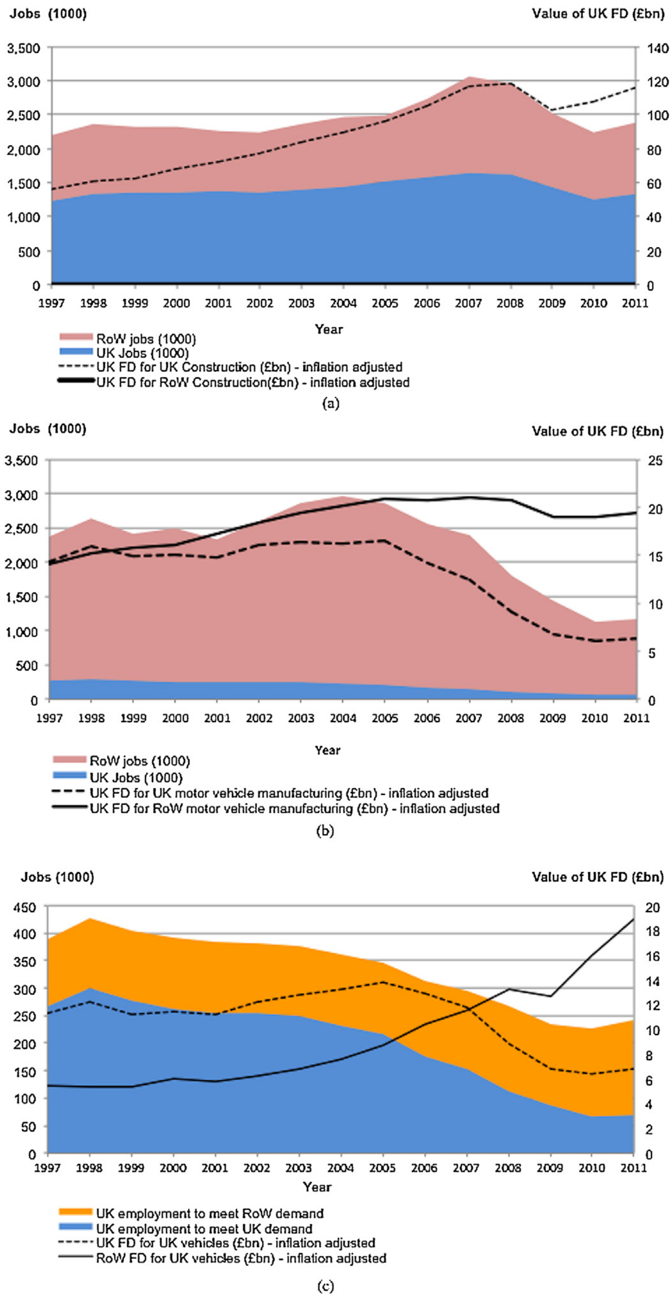

Fig. 4. (a) MRIO modelling results showing historical domestic and international supply chain employment to meet UK demand for construction between 1997 and 2011. Inclusion of the value of UK final demand over the same period. (b) MRIO modelling results showing historical domestic and international supply chain employment to meet UK demand for motor vehicles between 1997 and 2011. Inclusion of the value of UK final demand over the same period. (c) MRIO modelling results showing historical domestic and international UK motor vehicle manufacturing supply chain employment to meet UK and RoW demand between 1997 and 2011. Inclusion of the value of UK and RoW final demand over the same period.

The low cases in both material efficiency initiatives showed a negligible change in labour requirements. The high case for reused steel sections showed a small positive increase of around 3000 additional full time workers in the UK construction sector. This was due to the higher labour intensity of deconstruction compared to demolition. However, the modelled change in construction sector employment was small relative to actual historical annual fluctuations in employment shown in Fig. 4a and seasonal fluctuations reported by the ONS. In 2012, all construction sector employment, including self-employment, varied by 70,000 workers (ONS, 2012b). In the modelling exercise, the change in total domestic and international labour requirements in the fabricated metals sector was small, less than 35 workers in both the low and high cases.

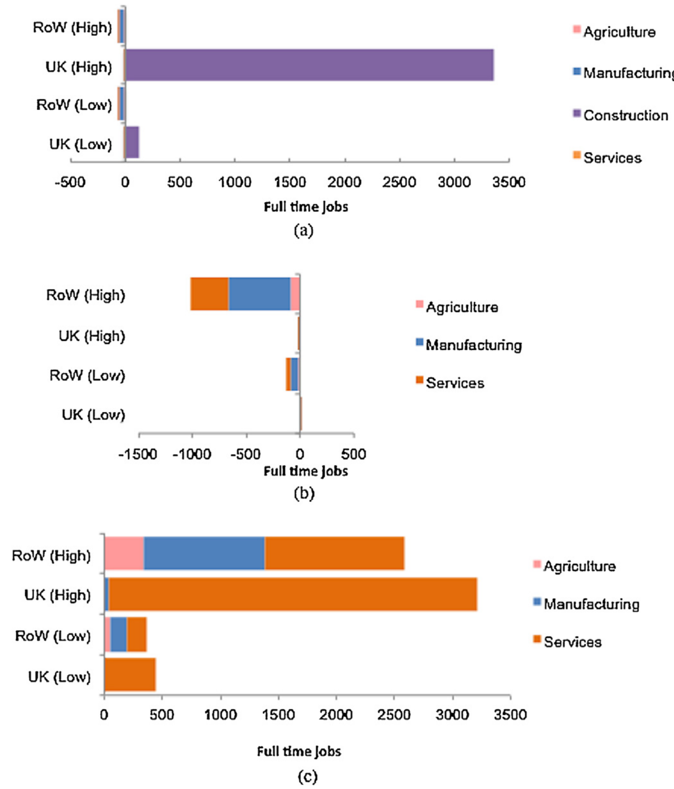

Fig. 5. (a) MRIO modelling results showing the net change in supply chain labour requirements for UK construction demanded in the UK as a consequence of increasing the amount of reused steel sections. (b) MRIO modelling results showing the net change in supply chain labour requirements for RoW vehicle manufacturing demanded in the UK as a consequence of increasing the number of car club members. (c) MRIO modelling results showing the net change in supply chain labour requirements for UK rental and leasing demanded in the UK as a consequence of increasing the number of car club members.

Although the modelling approach doesn't include any price changes and associated rebound effects, it is reasonable to assume that the additional time to deconstruct, clean and test steel sections might increase the cost of construction projects using reused steel. However, it is unclear how this would change over time, for example if the emerging market for reused steel experienced economies of scale. It is unlikely that the proposed rate of steel reuse in the modelling exercise would influence the price of new steel as this is largely driven by global supply trends. Further work could be conducted to see if the domestic market for steel scrap would be impacted by a fall in the supply of steel sections.

The modelling results for the car club case study show a non-negligible change in labour requirements in the UK rental and leasing supply chain and the RoW motor vehicle manufacturing supply chain. These modelling results show that the UK motor vehicle manufacturing supply chain employment is fairly insulated from changes in UK demand for car sharing. This is because UK cars are predominantly exported. Over half of the increases in UK labour requirements in the modelled case studies are in the rental and leasing sector and retail and repair of vehicles sector. Car clubs shift private vehicle purchases by households to vehicle purchases by car clubs. Fig. 5b and c show a fall in employment in the RoW motor vehicle manufacturing supply chain to meet UK demand but an increase in employment in the rental and leasing supply chain. The results show a modest net increase of 1500 RoW full time jobs across both supply chains.

A key point to note is that the car club case study might actually increase the number of new vehicles purchased in the UK. Interviewees indicated that due to higher usage rates and customer perceptions around vehicle conditions, car clubs vehicles are replaced on average every 12 months. Private vehicle displacement rates of new vehicles would need to be sufficiently high to ensure that the high annual turnover of car club vehicles would still result in a net reduction in new vehicle purchase rather than a displacement from private to shared ownership.

Again, the modelling results do not show how the UK might transition to a higher number of car sharers or any potential rebound effects. Of potential importance are the impact of increased car club members on the volume and prices of cars in the second hand market. Assuming all car club vehicles were retired after a year of use, the volume of 0–2 year old cars in the second hand market could increase by around 2% (University of Buckingham, 2013). It is unclear if this would impact on prices of vehicles in the second-hand market. Further research is therefore required to gather evidence on these and other feedback mechanisms, which can be used to make informed assumptions in future modelling work.

4.3. Modelling limitations

Due to limited data availability, many proposed changes to the supply chain detailed in Table 4 could not be modelled or were estimated from a single source. For example, in the reuse case study, transportation, cleaning, certification, storage, specifying and sourcing of steel were all omitted from the analysis. It is reasonable to assume these all activities would be conducted in the UK, as transporting steel over longer distances would increase costs and reduce the incentive to select reused steel sections over new steel. The modelling work also omitted any potential employment impacts associated with reusing other materials in construction since deconstruction could increase the salvageability of all materials. As only part of the changes to the supply chain could be modelled and induced impacts are omitted, the change in domestic labour requirements in the reuse case study is likely to be an underestimate.

There are also uncertainties regarding the underlying the model data. van den Brink and Anagboso (2010) note the employment in the construction sector is challenging to accurately estimate as the ONS's method of data collection tends to underestimate the output of small businesses and around 40% of the construction sector are self-employed sole traders.

For simplicity, the model also includes the assumption of no net change in supply chain costs. Even in the case of employment creation, total value added was held constant so any increase in the sector wage bill was offset by an equivalent reduction in taxation and/or profit. In reality this is highly unlikely and even if the net impact on sector costs were zero, firms within the sector would be impacted differently as they are non-homogenous.

The model also assumes that all labour requirements increases linearly with output, ignoring any productivity gains or economies of scale. While this might be true for some roles, in reality it does not hold for all sectors. Interviews with car club operators revealed that the labour requirement in many of their business functions were either unrelated or non-linearly related to the number of car club members. It should also be noted that interview responses are only useful for characterising current understanding of these two material efficiency strategies. There are additional uncertainties regarding how these strategies might be scaled up, which may not be fully reflected in the interview responses because of the lack of precedent.

The chosen modelling approach is useful for providing a first indication of the likely scale and location of immediate changes in direct and indirect supply chain employment but there is a high degree of uncertainty regarding how these sectors may transition to more materially efficient practices and how prices and demand may evolve. It is for this reason that the results are presented as 'potential supply chain employment impacts'.

5. Discussions and conclusions

The multi-method approach used in this study also provides important insights for both researchers and policymakers undertaking further research on the employment impacts of material efficiency strategies. First, the mode of implementation is extremely important. For example, car club are perceived to improve material efficiency because they encourage greater intensity of use. However the interviews and modelling results show they may actually confound this assertion because they increase demand for new as opposed to second-hand vehicles. To ensure car clubs are materially efficient, car club vehicles would need to be replaced infrequently and/or personal vehicle displacement rates would need to be high.

Second, there may be trade-offs associated with different modes of strategy implementation, which need to be understood and evaluated. Continuing with the example of car clubs, the potential for supply chain employment creation would be dependent on how the car club operates. Car clubs that rely more on technology platforms to rent out car club vehicles, often the case with peer-to-peer car sharing, would create fewer job opportunities than those operators who rent out vehicles using call centres. However, peer-to-peer car sharing would be more materially efficient as no new vehicles are bought for use in the car club fleet.

Finally, further research is required to assess the likely evolution of supply chain costs and any rebound effects. For example, the reuse case study showed potential employment creation would be concentrated in the construction sector because of the assumption that all buildings in the UK were deconstructed rather than demolished. However, one of the described limitations to the modelling is the assumption that supply chain costs are held constant. Skelton and Allwood (2013) show that there is little incentive to introduce material efficiency strategies along the supply chain because labour costs are relatively higher than material costs. Therefore there is likely to be little incentive to increase labour costs further by employing more deconstruction workers to salvage steel. A simple modelling technique such as MRIO is therefore useful for highlighting where further research is required to develop realistic assumptions for use in more complex models. In this case study, a useful piece of future research could focus on developing estimates of deconstruction costs, labour requirements and steel salvage rates across different building types in the UK.

To conclude, the modelling results from the two case studies show that material efficiency may not have an adverse effect on domestic employment. The multi-method approach used in this study has also highlighted that there are many factors that influence the employment consequences of material efficiency strategies, including the rate, geographical spread and mode of deployment. It has also outlined some of the many uncertainties associated with accurately modelling future employment impacts of a change in material demand. In spite of these uncertainties, further research in this area is needed to understand the impact of these factors and ensure that member states are introducing initiatives that meet both environmental and economic ambitions outlined in the European Commission roadmap for a Resource Efficient Europe.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resconrec.2015.11.014.

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Further reading (websites)

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⟨http://www.citycarclub.co.uk/about/what-does-it-cost⟩ (accessed 16/06/15).
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