SUPPORTING INFORMATION FOR:

Cooper, D. R., N. Ryan, K. Syndergaard, Y. Zhu. 2020. The potential for material circularity and independence in the U.S. steel sector. *Journal of Industrial Ecology.*

Summary

This supporting information contains information useful to understanding the themes and numbers introduced in the main article. This document is 61 pages long and contains 22 tables and 32 figures.

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Section S1-1: U.S. end-of-life recycling rates

End of life (EOL) recycling rates (RR) found in the literature are summarized in Table S1-1 and shown in this section to provide context. Global RRs defined for 2007 by the World Steel Association (2010) are used in the global steel analyses by Pauliuk et al. (2013) and Daehn et al. (2017). Both of these studies are referenced in the main manuscript.

Table S1-1: Global and U.S. specific EOL RRs presented in the literature

Scrap category	Scope	Year	EOL recycling rate	Reference
Total	Global	2007	0.5-0.8	Wang et al. (2007) – Yale Center for Industrial Ecology
Construction	Global	2018	0.82	Elshkaki et al. (2018) – Yale Center for Industrial Ecology
Machinery	Global	2018	0.82	Elshkaki et al. (2018) – Yale Center for Industrial Ecology
Transport	Global	2018	0.87	Elshkaki et al. (2018) – Yale Center for Industrial Ecology
Metal goods	Global	2018	0.58	Elshkaki et al. (2018) – Yale Center for Industrial Ecology
Total	Global	2006	0.65	Allwood et al. (2010)
Construction	Global	2007	0.85	World Steel Association (2010)
Automotive	Global	2007	0.85	World Steel Association (2010)
Machinery	Global	2007	0.9	World Steel Association (2010)
Appliances	Global	2007	0.5	World Steel Association (2010)
Containers	Global	2007	0.69	World Steel Association (2010)
Appliances	U.S.	2014	0.89	USGS (2016)
Containers	U.S.	2014	0.70	USGS (2016)
Structural beams and plates from	U.S.	2014	0.98	USGS (2016)
Reinforcement bar and other materials	U.S.	2015	0.71	USGS (2016)
Total	U.S.	1998	0.52	USGS value reported by Bowyer et al. (2015)
Total	U.S.	2007	0.9	Steel Recycling Institute reported by Bowyer et al. (2015)
Total	U.S.	2004-2009	47.5/87.2 = 0.55	Damuth (2011) reported by Bowyer et al. (2015)
Construction	U.S.	2004-2009	1-0.32 = 0.68	Damuth (2011) reported by Bowyer et al. (2015)

Section S1-2: Additional data for U.S. steel DMFA

Product lifespans

The product lifespan scenarios for each of the sectors are shown in Table S1-2. This study uses normal lifespan distributions. Different product lifespan distributions have been used in previous DMFAs (e.g., beta, log-normal, normal, Weibull, Gaussian). Müller et al. (2014) present a review of studies that investigate the effect of choosing different lifespan distribution functions on DMFA model results. They found either that DMFA model results are insensitive to the choice of product lifespan distribution or that findings were most sensitive to mean lifetimes themselves. Additionally, sensitivity analyses are presented by both Müller et al. (2011) and Müller et al. (2006) on the effect of the lifetime distribution function (normal, log-normal and Weibull) and mean lifetime on calculated in-use stocks. In both studies, they found that calculated stocks are sensitive to the modeled mean product lifespans but not the choice of lifespan distribution. Normal distributions are a popular choice for modeling product lifespans in the literature and are used by Pauliuk et al. (2013), Müller et al. (2011), Müller et al. (2006), and Yin and Chen (2013). Mean product lifespans and lifespan standard deviations are extracted from these above studies and used in this article.

Table S1-2: Product mean lifespan for each scenario used in this study's DMFA normal lifetime distributions.

Product Category	Lifespan scenario (years)					
	Baseline		Long		Short	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Construction	75	25	97.5	32.5	52.5	17.5
Transport	20	7.5	14	5.25	26	9.75
Machinery	30	10	21	7	39	13
Other	15	5	10.5	3.5	19.5	6.5

True consumption in different end-use sectors

The amount of true consumption attributed to each end-use sector can have a significant impact on the DMFA results because products in different end-use sectors have very different lifespans (e.g., steel I-beams within 'construction' versus steel packaging cans within 'metal goods'). Challenges encountered when estimating the sectoral breakdown of true consumption using primary data sources include the focus of many sources on the final product destinations of domestically produced steel (ignoring imports) and the tendency to assign large percentages of demand not to a specific end-use sector but to 'service centers' or 'other.' Only more recent data from the *American Iron and Steel Institute* (AISI) do not include the 'service center' classification. Therefore, in this article we assign the sectoral breakdown of true consumption according to the average of AISI's estimates from their yearly profiles (2014-2017), see Table S1-3. These values are assumed constant between 1880-2017, which is an assumption also made by Pauliuk et al. (2013), who also use AISI data sources for the U.S. sector split in their global steel use study. It is also assumed in this study that the same sector split applies to internationally traded goods as well as domestically produced steel products. This assumption was also made in Müller et al.'s (2006) study.

Table S1-3: Sector split used in flow-driven DMFA (AISI, 2015, 2016, 2017, 2018)

Product Type	AISI (avg. 2014-2017)
Construction	42%
Transport	27%
Machinery	17%
Products	14%

Historical U.S. true consumption

Annual total U.S. true consumption steel values are estimated for 1880-2017. Table S1-4 summarizes the data sources and methodology used to estimate true consumption for the different years.

Table S1-4: Data sources and methods used to estimate historical U.S. true consumption

Year	**Calculation of true consumption**	**Data sources**
2017	Apparent Consumption (AC) + Indirect trade (IT)*	United States Geological Survey (AC) + Comtrade (IT)
2002-2016	True Consumption (TC)	World Steel Yearbook (TC)
1991-2001	Apparent Consumption (AC) + Indirect trade (IT)*	United States Geological Survey (AC) + Comtrade (IT)
1962-1990	U.S. Net Domestic Supply minus other product imports and exports (NDS) + Indirect trade (IT)*	American Iron and Steel Institute (NDS) + Comtrade (IT)
1940-1961**	Domestic Shipments (DS) + Net Steel Imports (NSI)	American Iron and Steel Institute (DS & NSI)
1932-1939**	U.S. Production x Yield***	American Iron and Steel Institute
1930-1931**	Domestic Shipments (DS) + Net Steel Imports (NSI)	American Iron and Steel Institute (DS & NSI)
1912-1929**	Production Steel Ingots & Casting x Yield*** + Imports/Exports	American Iron and Steel Institute
1880-1911**	Production Steel Ingots & Casting x Yield***	American Iron and Steel Institute

*The steel embedded in net indirect imports was converted into the quantity of steel used to manufacture these goods by dividing by 0.84 (as explained in the main manuscript)
**Indirect trade is not included in true consumption estimates for these years as the net contribution is assumed to be negligible
*** Yield value of 0.93 used, based on Cullen et al.'s (2012) rolling/forming losses

The World Steel Association estimate U.S. true consumption in their annual Statistical Yearbook but this data only exists for 2002-2016. The World Steel Association has yet to calculate true consumption for more recent years. Therefore, for all other years, the true consumption was estimated in this study using a combination of data on shipments, apparent consumption, production, yields, and indirect net imports in order to estimate true consumption dating back to 1880.

The steel embedded in net indirect imports is calculated using the United Nations Commodity Trade (Comtrade) database for 1962-2001 and 2017. Indirect trade is calculated from the Comtrade database by mapping the trade of 29 commodities ranked by global import, all having global imports greater than 1,000 Gg iron per year (United Nations, 2018; Wang et al., 2007b). These categories are a subset of the 220 categories Wang et al. (2007b) used when characterizing iron cycles. Table S1-5 lists the commodity codes, part descriptions, percent iron and mass to value ratios.

For 15 of the categories in 2017, Comtrade reports the quantity imported and exported in kilograms but they report U.S. dollar values for all commodities listed in Table S1-5. As described fully in Section S5 (Indirect imports of steel in finished goods), a series of regression analyses are performed on the depedence of the steel intensity (kgs steel per traded U.S. dollar) in the 15 known categories on a range of product attributes (product category, steel fraction by mass, level of fabrication, and complexity of the energy conversion systems in the product). The results were used to estimate the steel intensity for the other 14 product categories (see Table S).

In order to calculate the mass imported and exported of the different import and export categories we multiplied the traded dollar values by the mass to dollar ratios (steel intensity) listed in Table S1-5. However, these mass values and those directly reported by Comtrade are in terms of steel embedded in final goods. Therefore, to translate the mass of imports and exports for each commodity to true consumptions values we divided by the ratio of steel 'in end-use products' to steel 'fabricated products' from Cullen et al. (2012). We then added the resulting mass values to World Steel Yearbook's apparent consumption to find total true consumption.

Table S1-5: Commodities mapped for indirect imports and exports. $ are 2017 U.S. dollars

SITC	STITC.1_Code	Parts or Final Product Descriptions	% Fe	Import kg/$	Export kg/$
S1	7321	Passenger motor cars, other than buses	0.65	0.05	0.04
S1	719	Machinery and appliances non electrical parts	0.75	0.11	0.13
S1	7328	Bodies & parts motor vehicles ex motorcycles	0.7	0.06	0.07
S1	698	Manufactures of metal	0.9	0.14	0.27
S1	729	Other electrical machinery and apparatus	0.55	0.03	0.03
S1	718	Machines for special industries	0.75	0.08	0.10
S1	7323	Lorries and trucks, including ambulances, etc.	0.8	0.10	0.11
S1	735	Ships and boats	0.9	0.12	0.15
S1	722	Electric power machinery	0.55	0.03	0.02

SITC	STITC.1_Code	Parts or Final Product Descriptions	% Fe	Import kg/$	Export kg/$
		and switchgear			
S1	7250	Domestic electrical equipment	0.65	0.06	0.08
S1	69421	Nuts, bolts, screws, rivets, washers of iron/steel	0.98	0.20	0.32
S1	7115	Internal combustion engines, not for aircraft	0.5	0.03	0.03
S1	693	Wire products ex electric & fencing grills	0.9	0.19	0.30
S1	7333	Trailers & other vehicles not motorized, & parts	0.5	0.12	0.11
S1	861	Scientific, medical, & optical instruments	0.55	0.03	0.03
S3	8213	Metal furniture	0.7	0.16	0.15
S1	7316	Rail. &tram. cars ,not mechanically propelled	0.85	0.18	0.22
S1	69221	Casks, drums, etc. used for transport of iron/steel	0.96	0.25	0.28
S1	715	Metalworking machinery	0.65	0.06	0.06
S1	714	Office machines	0.22	0.02	0.02
S1	724	Telecommunications apparatus	0.25	0.02	0.02
S1	712	Agricultural machinery and implements	0.7	0.07	0.08
S1	894	Perambulators, toys, games and sporting goods	0.2	0.07	0.02
S1	695	Tools for use in the hand or in machines	0.85	0.23	0.05
S1	6291	Rubber tires & tubes for vehicles and aircraft	0.15	0.04	0.04
S1	717	Textile and leather machinery	0.65	0.06	0.06
S1	7325	Road tractors for tractor trailer combinations	0.8	0.13	0.17
S1	69721	Domestic utensils of iron or steel	0.95	0.24	0.16
S1	69411	Nails, tacks, staples, spikes, etc. of iron or steel	0.98	0.46	0.60

In recent years, a significant proportion of U.S. steel true consumption has been from net indirect imports (e.g., 19.3% in 2017); however, this has not always been the case. Please note that Müller et al. (2006), in their analysis of historical U.S. iron stocks, ignored international trade prior to 1950 as they assumed it to then be negligible. In our study, we only exclude trade prior to 1940.

Aggregated stocks per capita (*spc*)

Historical *spc*, aggregated over the different sectors, are shown in Figure S1-1.

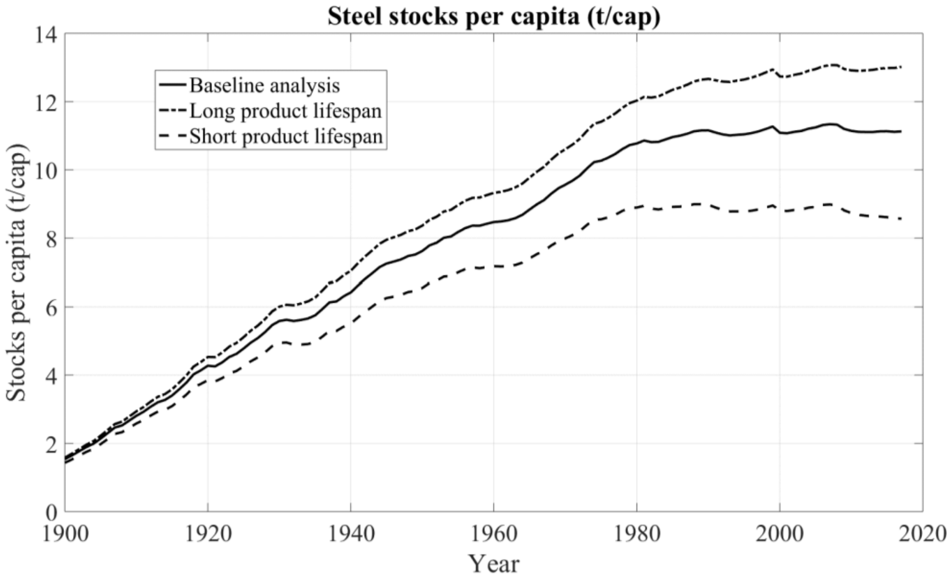

Figure S1-1: Historical stocks per capita (*spc*) aggregated over the end-use sectors

The aggregated *spc* values calculated for 2017 (8.5-13 t/capita) align with existing estimates from the literature (9.1-14.3 t/capita). Hatayama et al. (2010) estimate 9.1 t/capita in 2005. Müller et al. (2006) reference 12 t/capita since 1980. USGS estimate 14.3 t/capita for 2002 (USGS, 2005). Müller et al. (2011) estimate 10-11 t/capita for 2005. Regarding the *spc* saturation level, Müller et al. (2006) estimate 11-12 t/capita saturation level and Pauliuk et al. (2013) estimate 13.6 to 14.3 t/capita for 2008. The variation between the above estimates could be the result of different lifetime estimates, distributions, sector divisions, or the use of true consumption (rather than embedded steel) in demand estimates.

Per-capita stocks are extrapolated in the stock-driven DMFA because, as argued by Müller (2006), personal stocks are likely the main driver of the material cycle and more directly related to the provision of services than consumption alone. Extrapolated *spc* are shown in Figures S1-13-S1-24 and total stocks based on population scenarios are shown in Figures S1-25-S1-28. The results of the DMFA are shown in Figures S1-2-S1-12.

DMFA Results - Overview

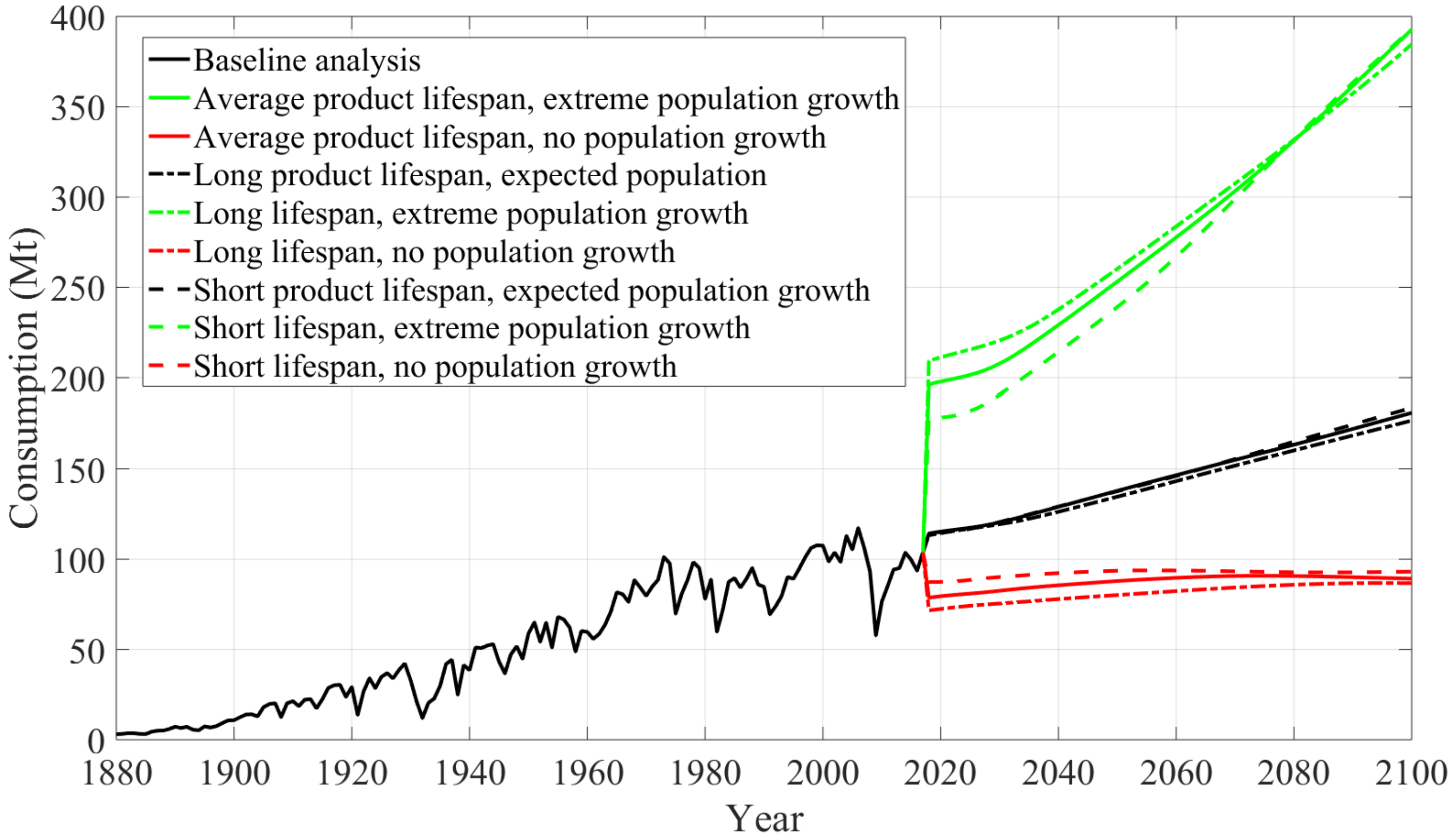

Figure S1-2: Historical and future U.S. steel consumption aggregated over the end-use sectors

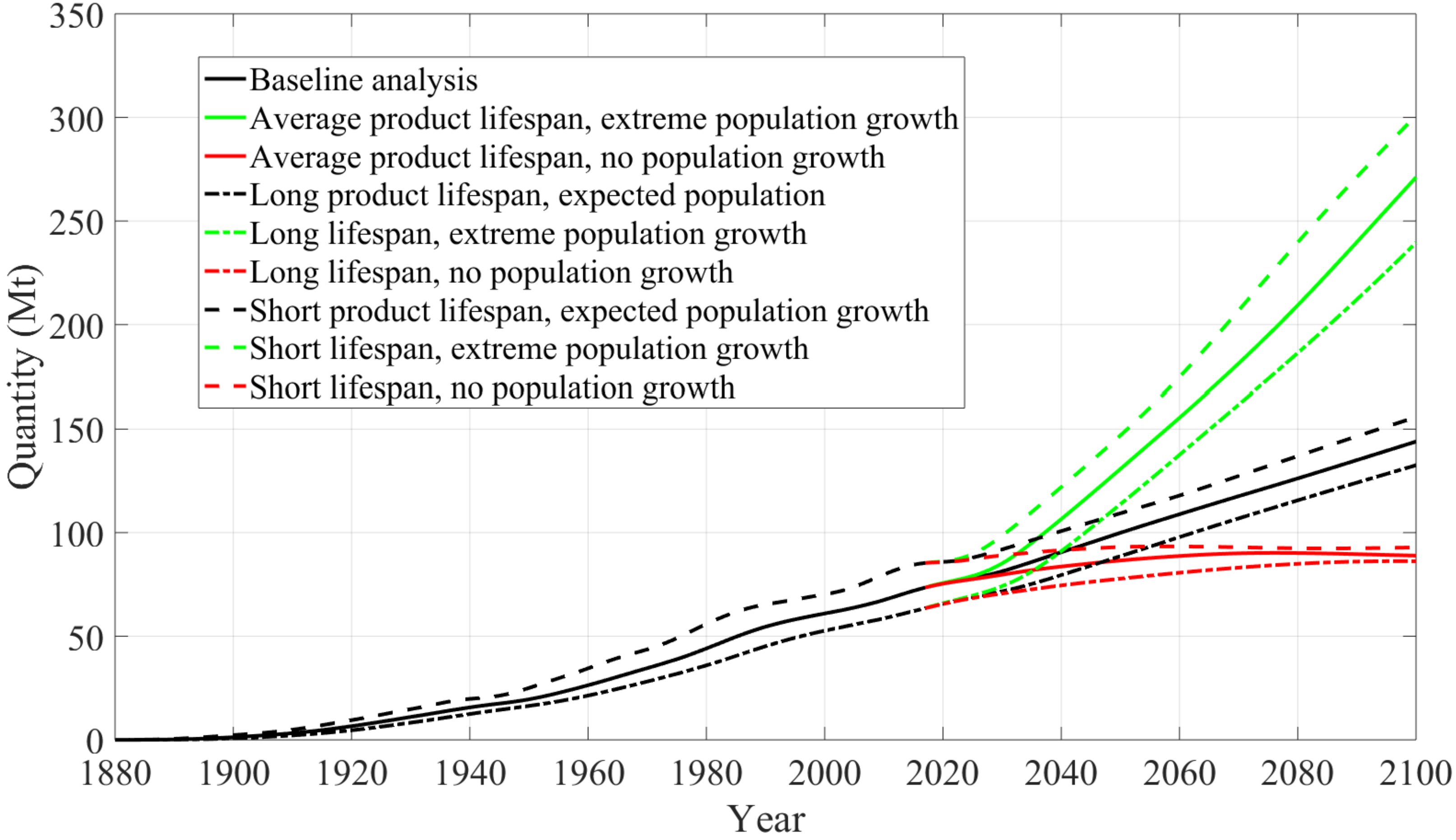

Figure S1-3: Historical and future U.S. steel scrap arising aggregated over the end-use sectors

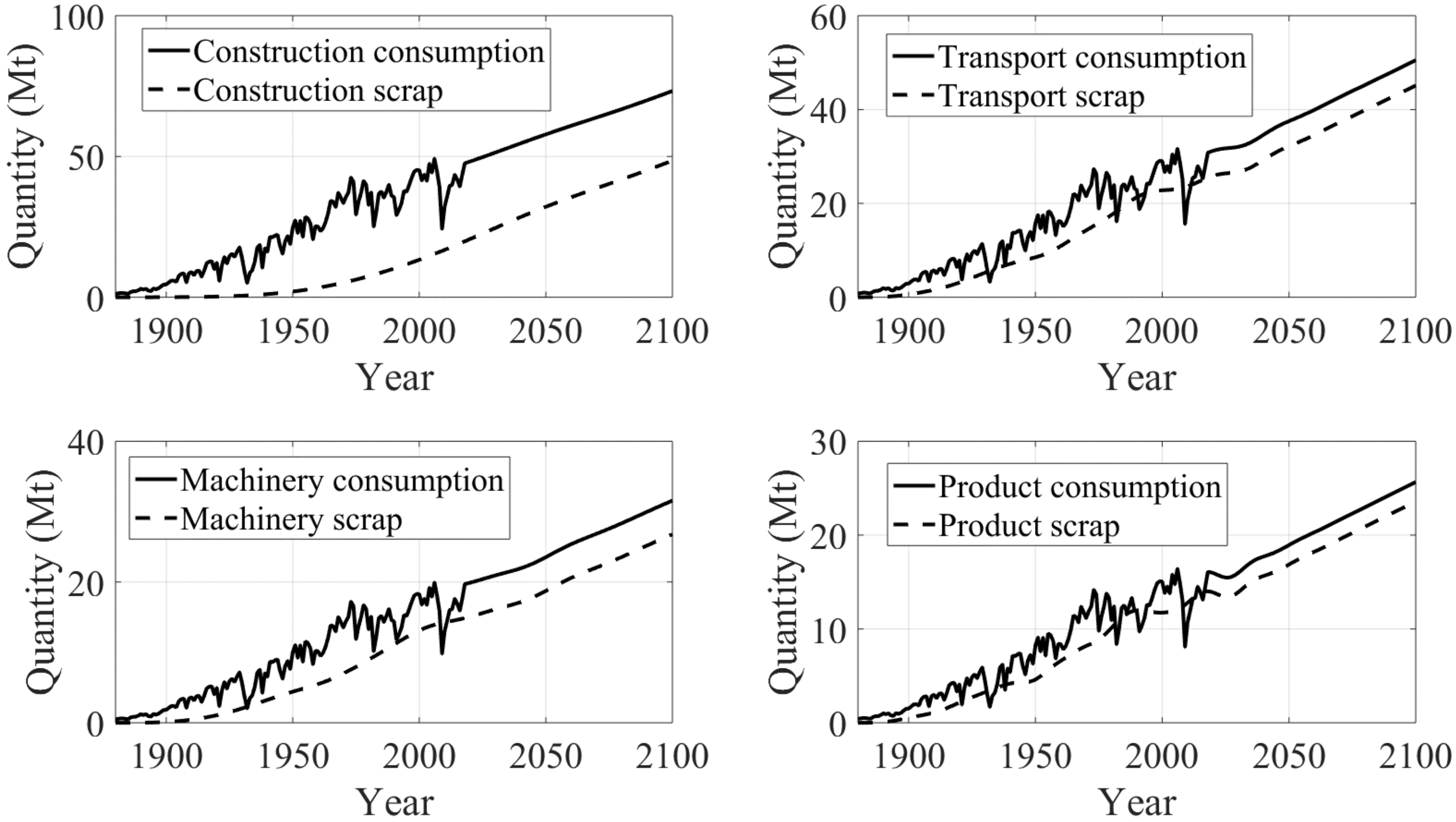

Figure S1-4: Baseline (expected population growth and product lifespan) DMFA results in the four end-use sectors

DMFA Results - Steel consumption

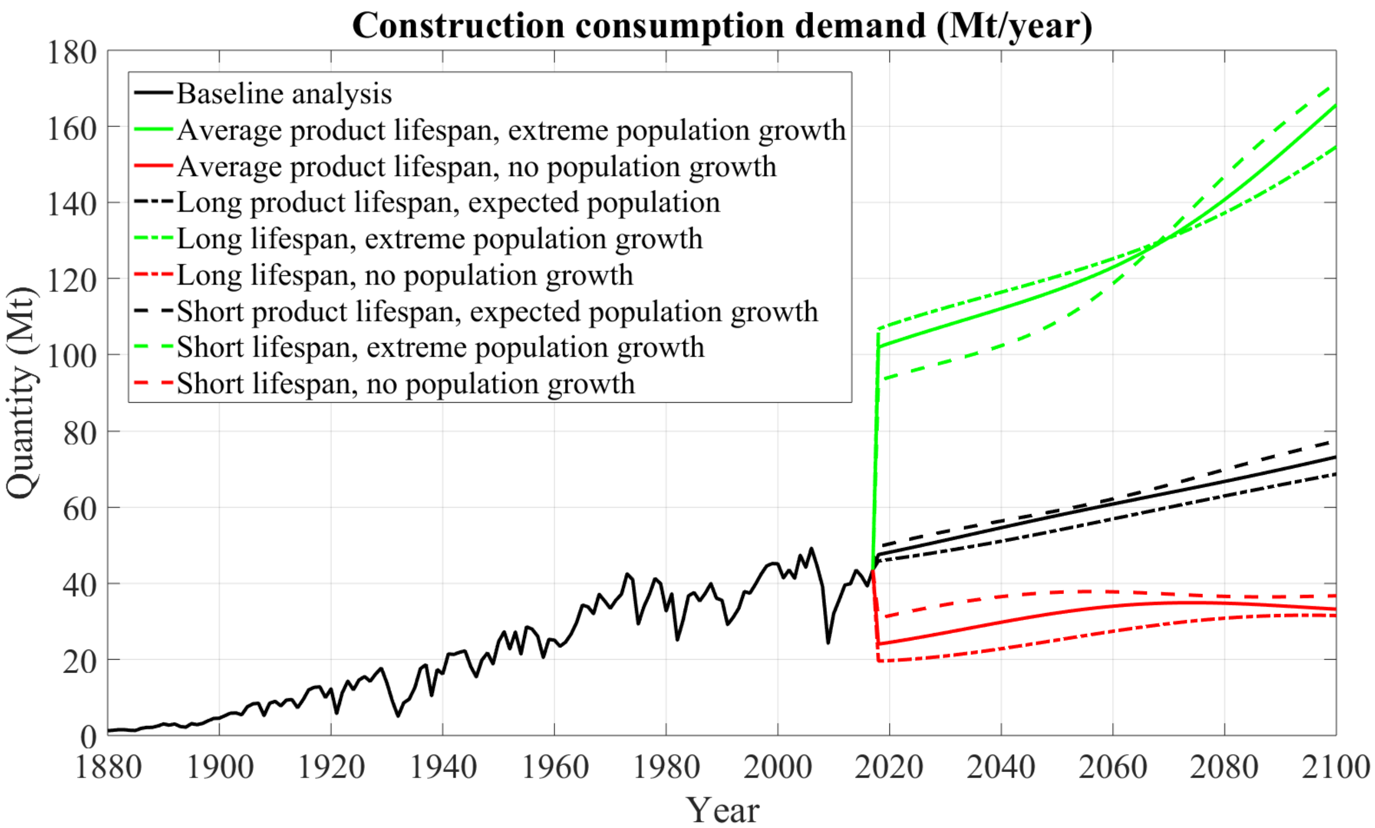

Figure S1-5: U.S. steel consumption in the construction sector

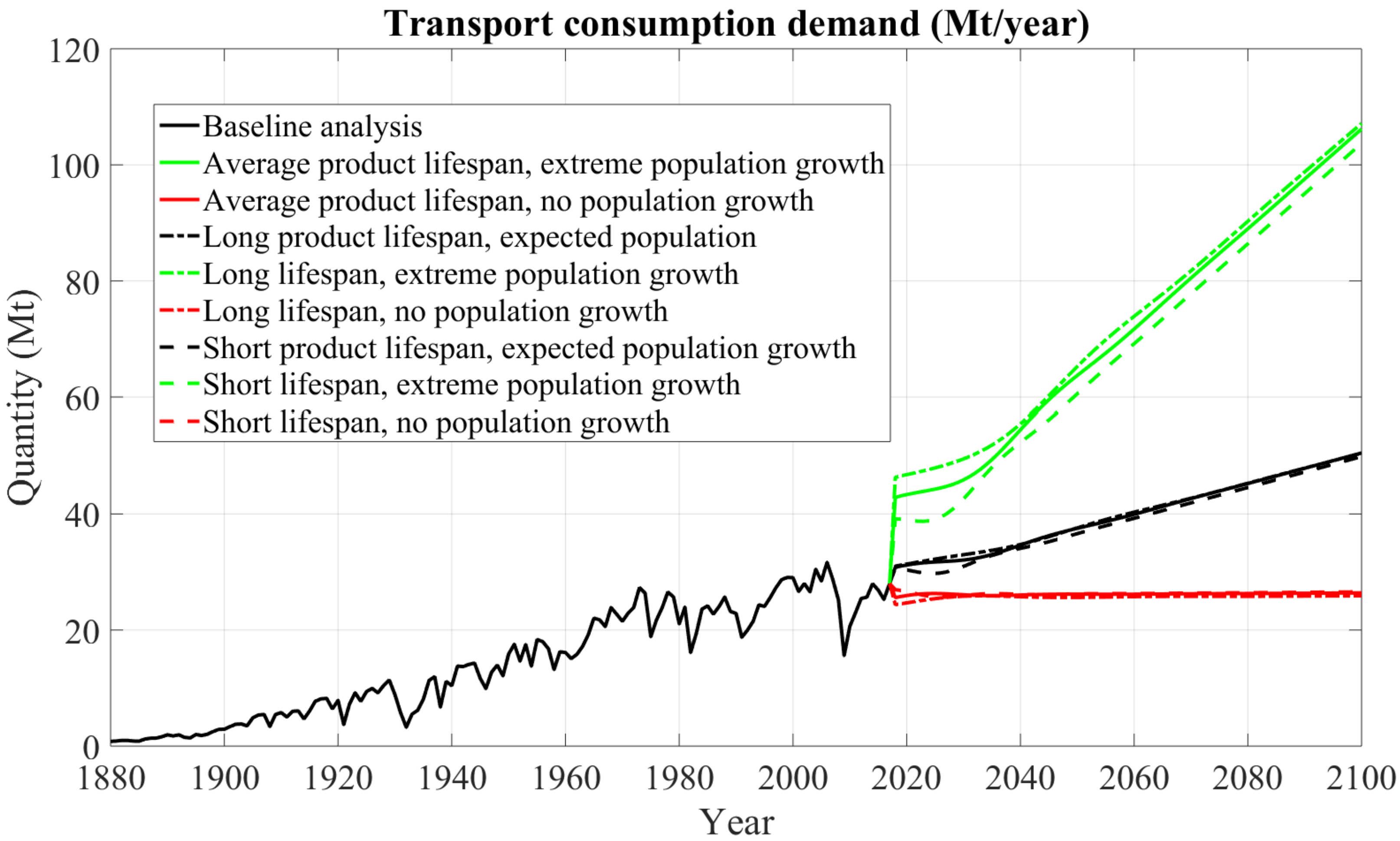

Figure S1-6: U.S. steel consumption in the transport sector

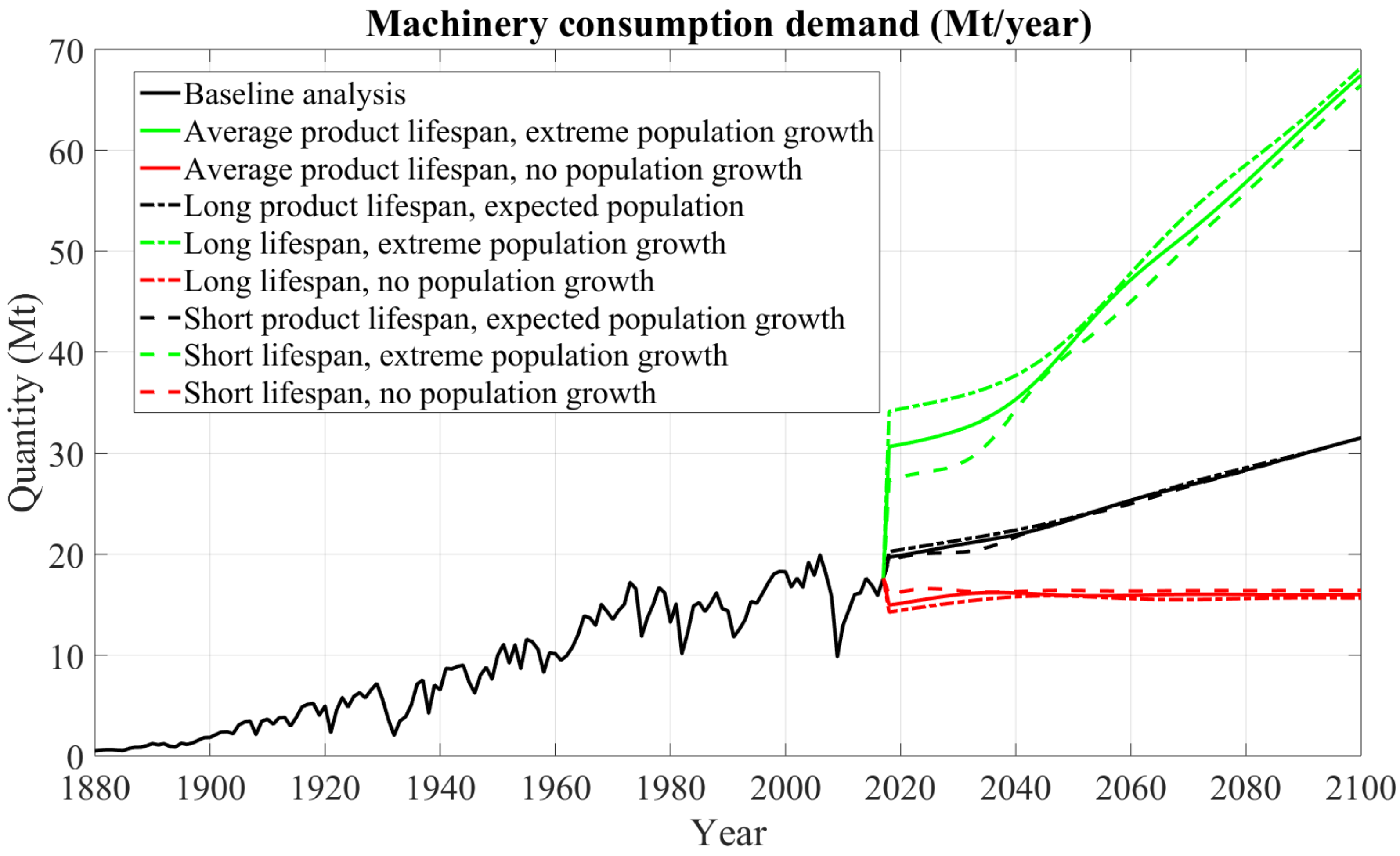

Figure S1-7: U.S. steel consumption in the machinery sector

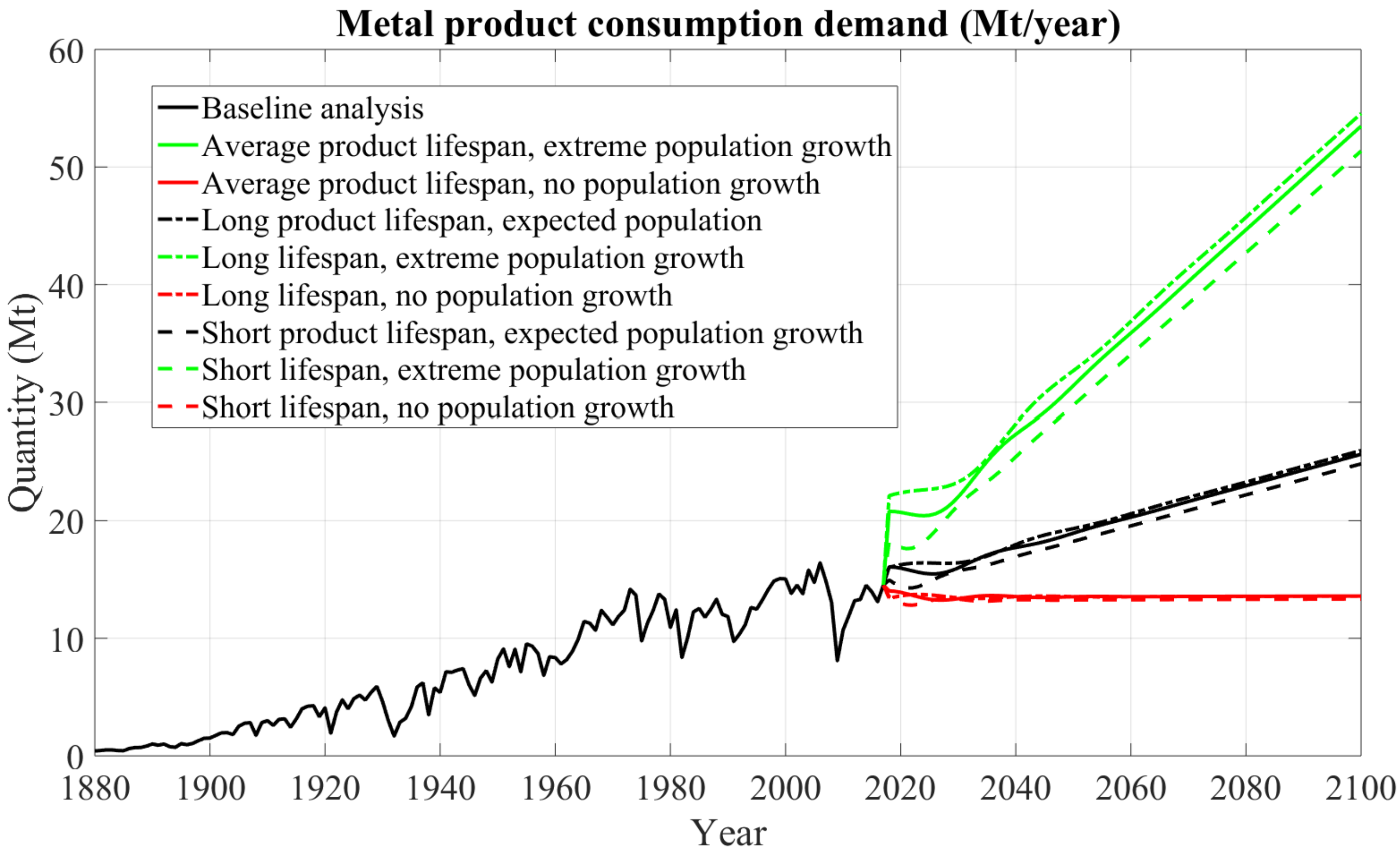

Figure S1-8: U.S. steel consumption in the metal goods (products) sector

DMFA Results - Steel scrap arising

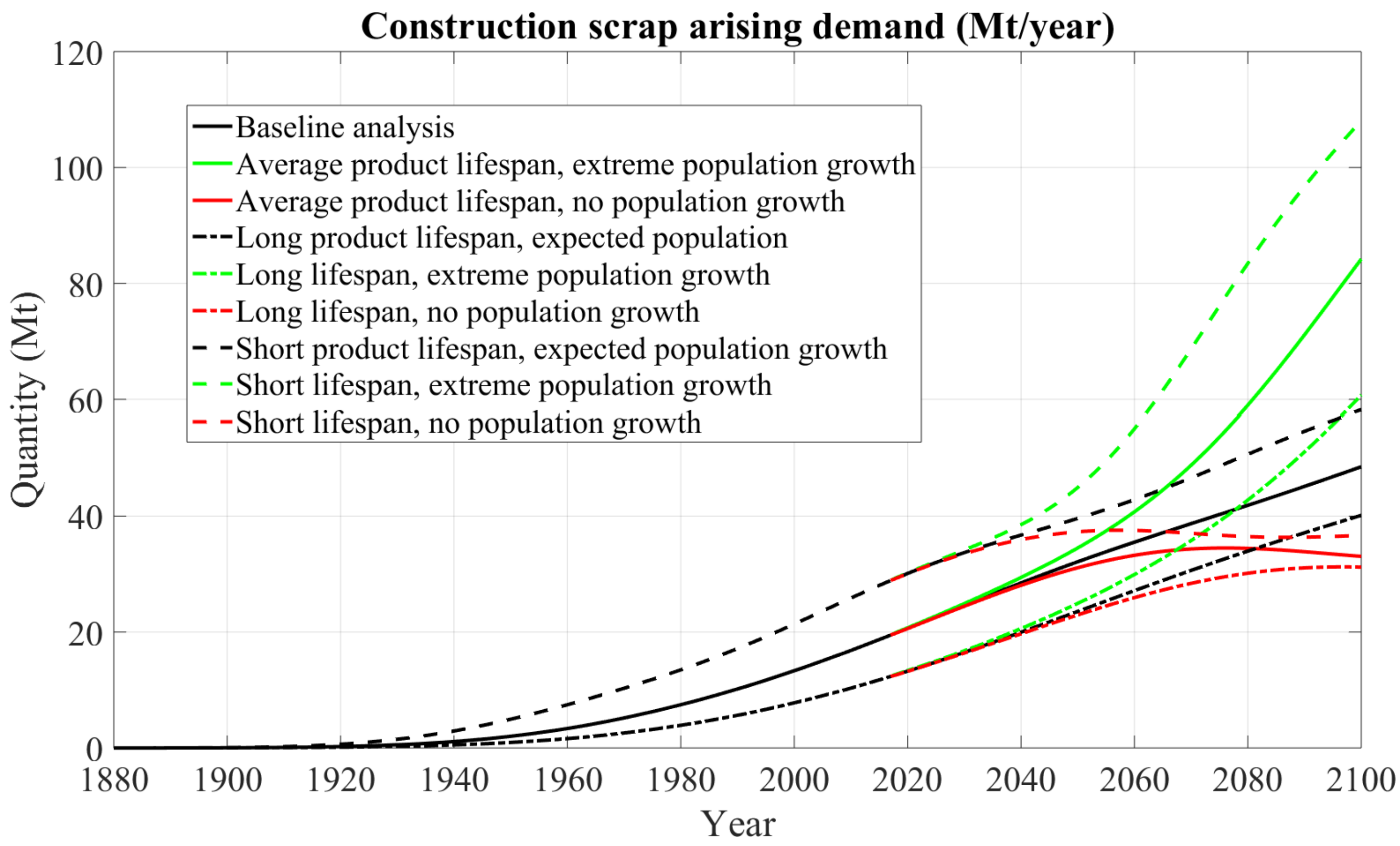

Figure S1-9: U.S. steel scrap arising in the construction sector

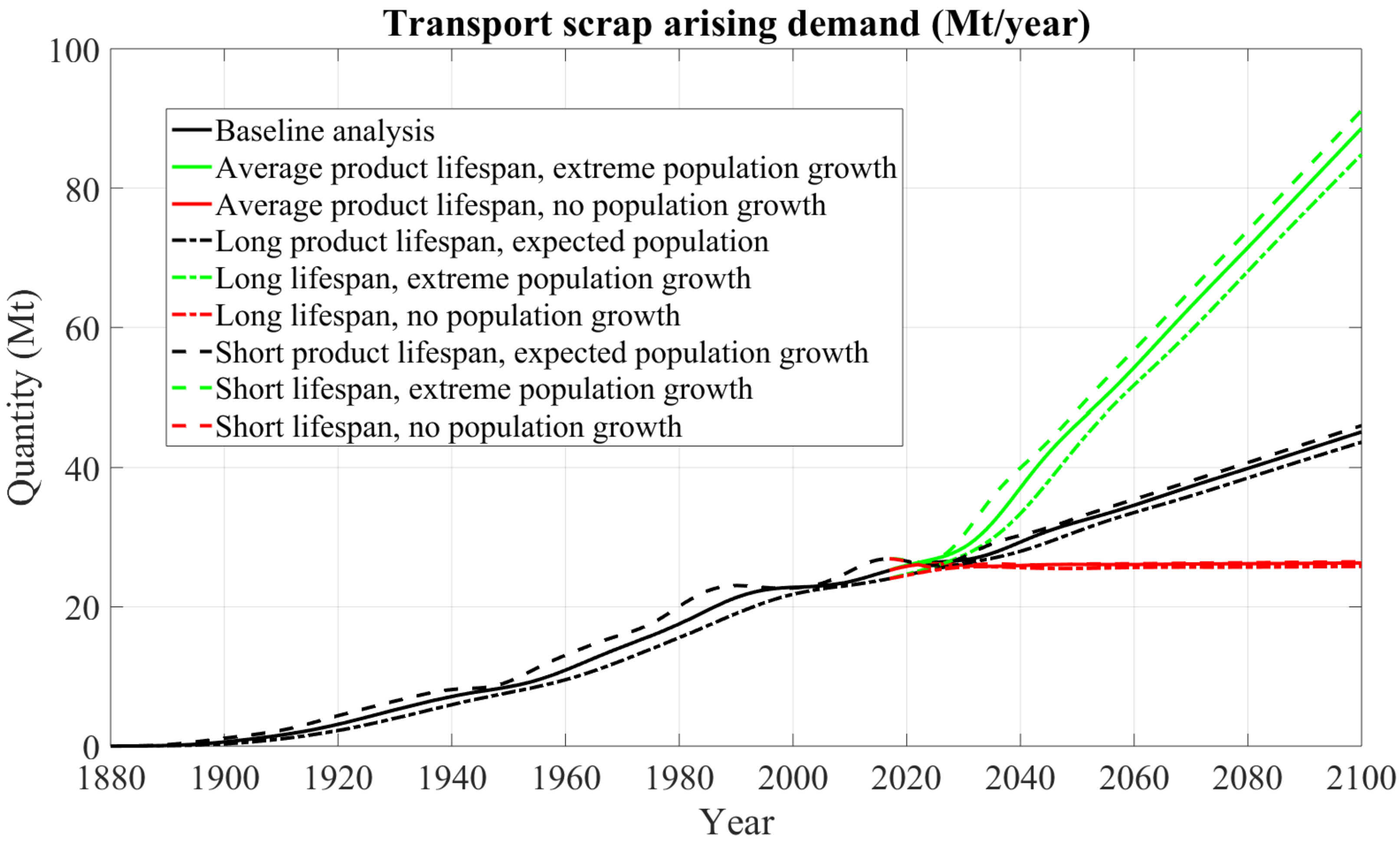

Figure S1-10: U.S. steel scrap arising in the transport sector

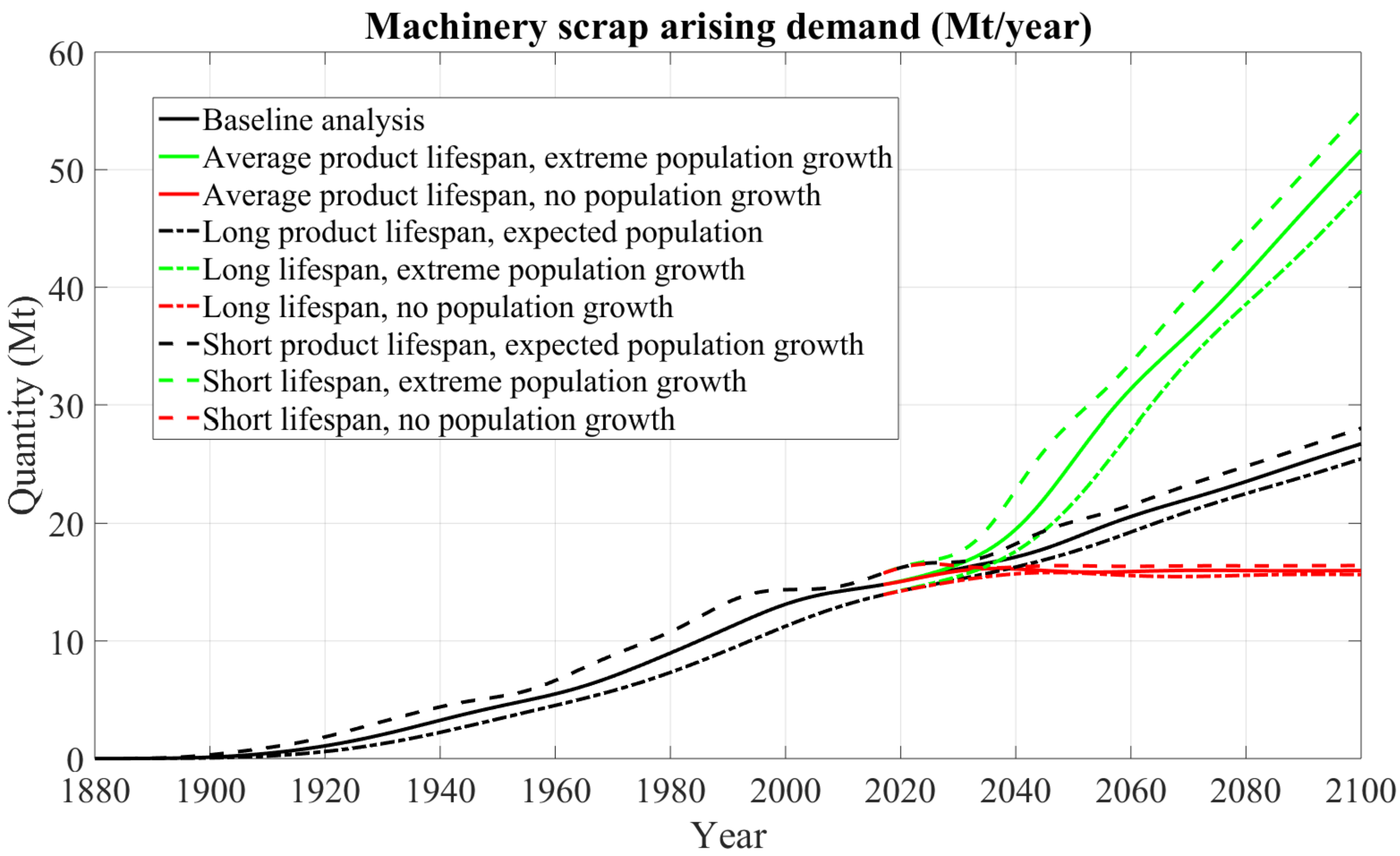

Figure S1-11: U.S. steel scrap arising in the machinery sector

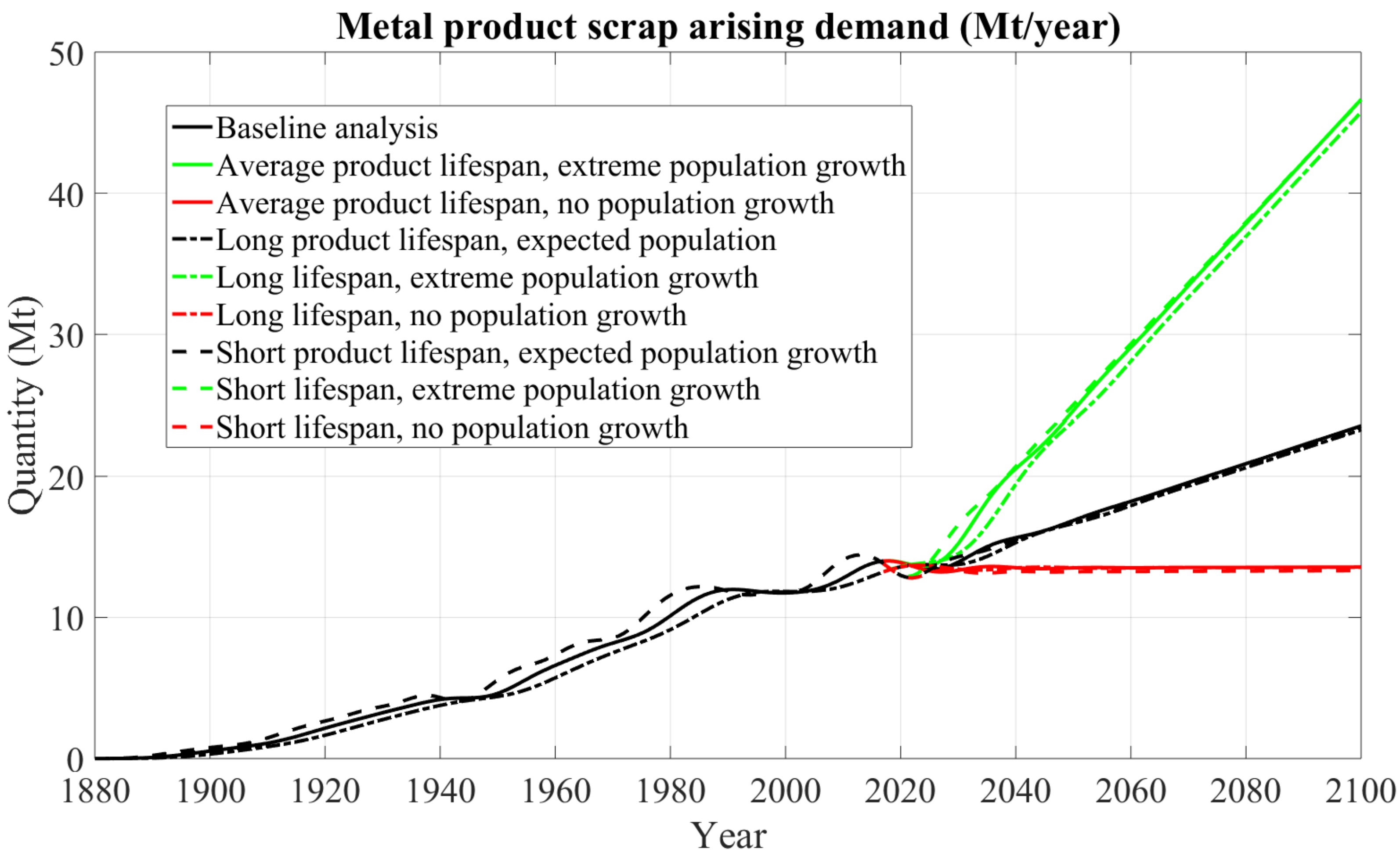

Figure S1-12: U.S. steel scrap arising in the metal goods (products) sector

DMFA Results - Steel stocks per capita

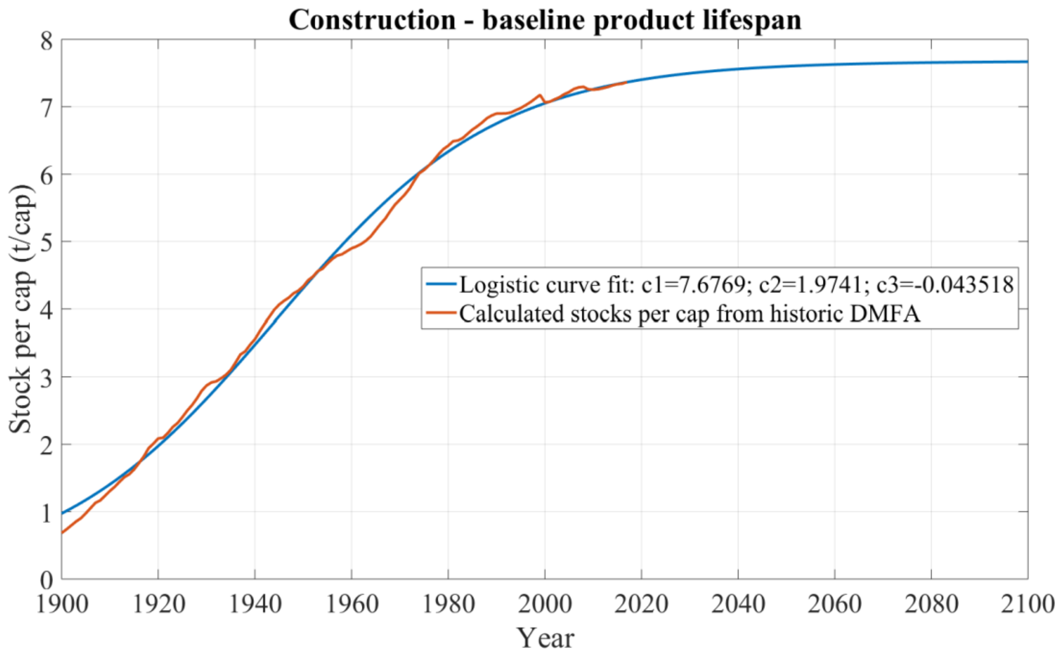

Figure S1-13: DMFA logistic curve fit to historical *spc* for the construction sector

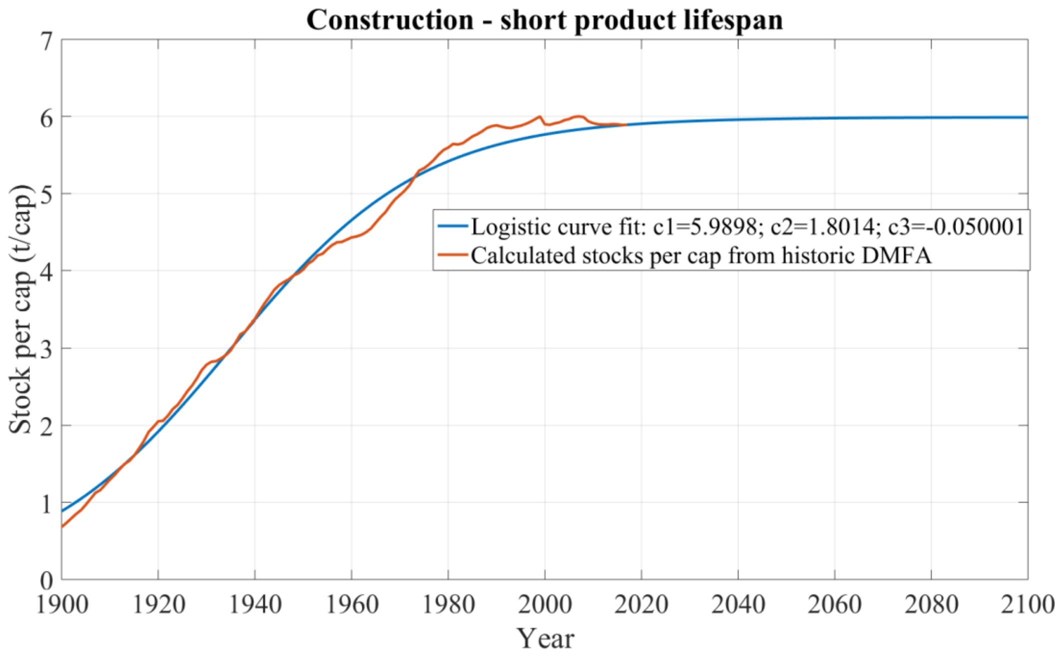

Figure S1-14: DMFA logistic curve fit to historical *spc* for the construction sector

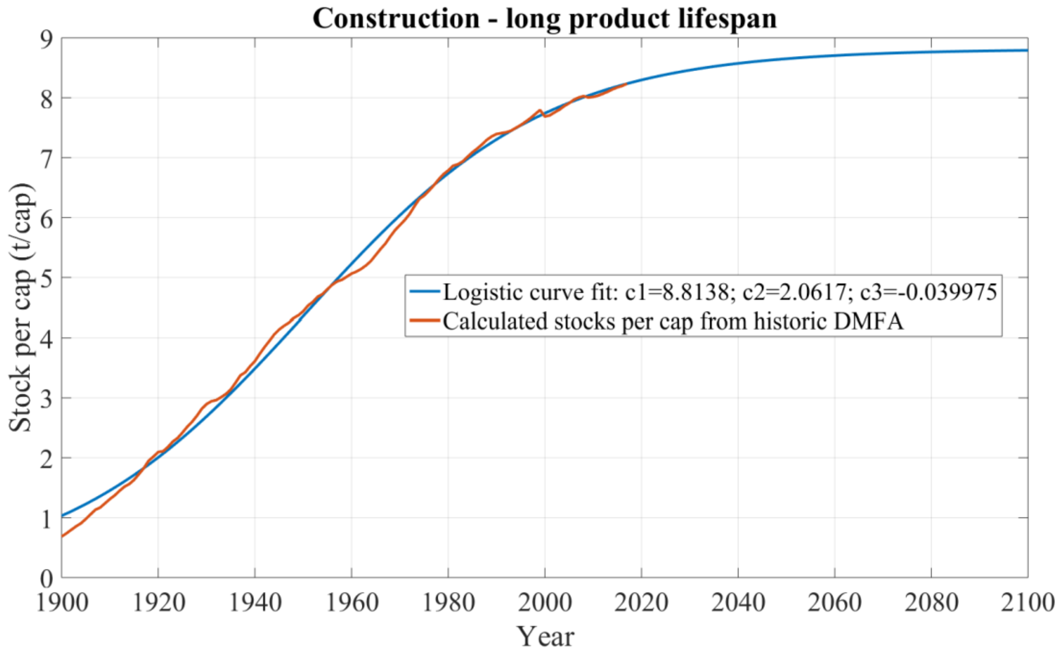

Figure S1-15: DMFA logistic curve fit to historical *spc* for the construction sector

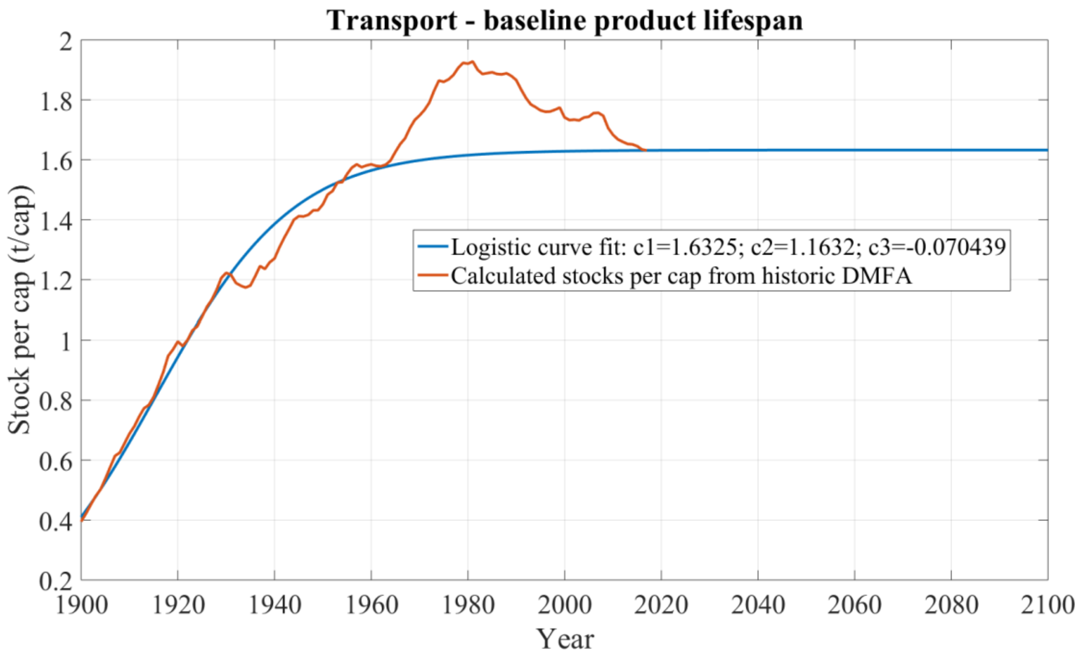

Figure S1-16: DMFA logistic curve fit to historical *spc* for the transport sector

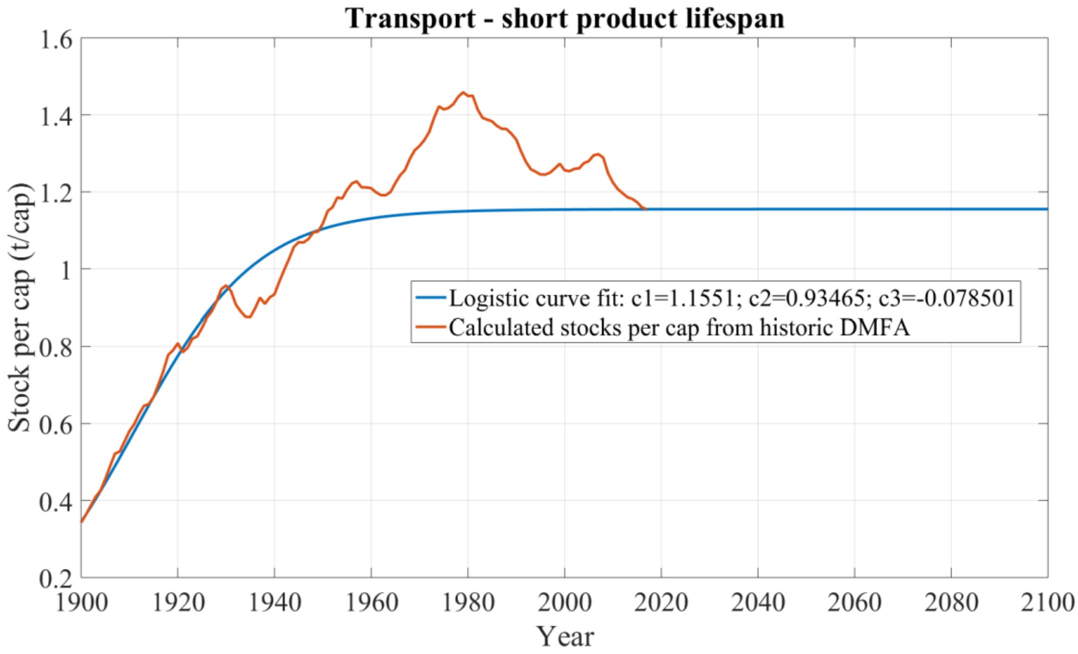

Figure S1-17: DMFA logistic curve fit to historical *spc* for the transport sector

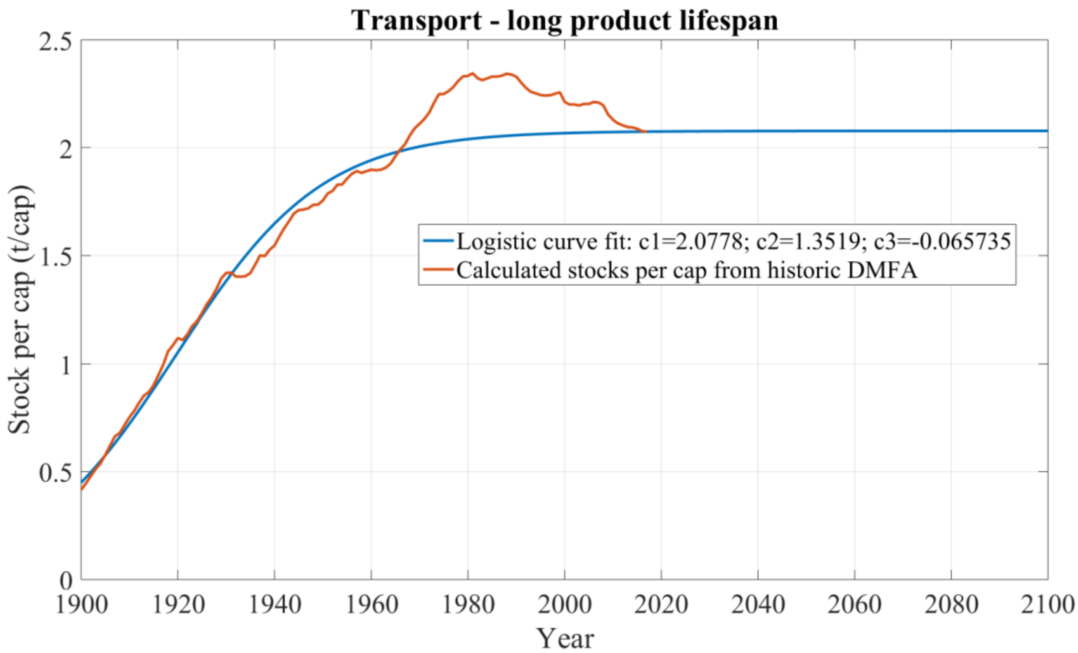

Figure S1-18: DMFA logistic curve fit to historical *spc* for the transport sector

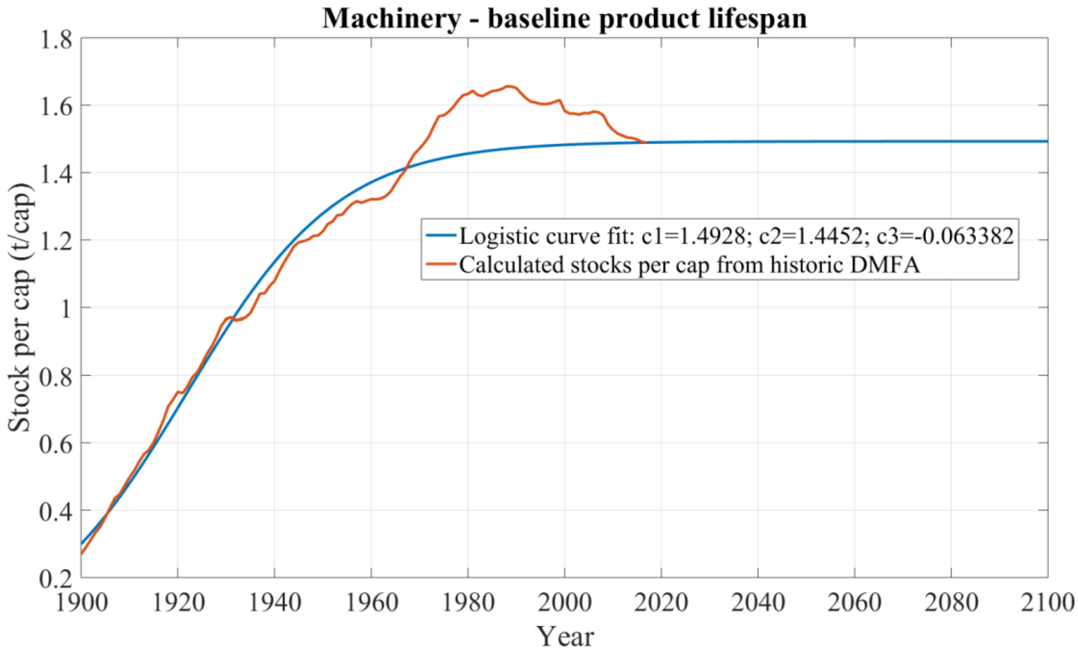

Figure S1-19: DMFA logistic curve fit to historical *spc* for the machinery sector

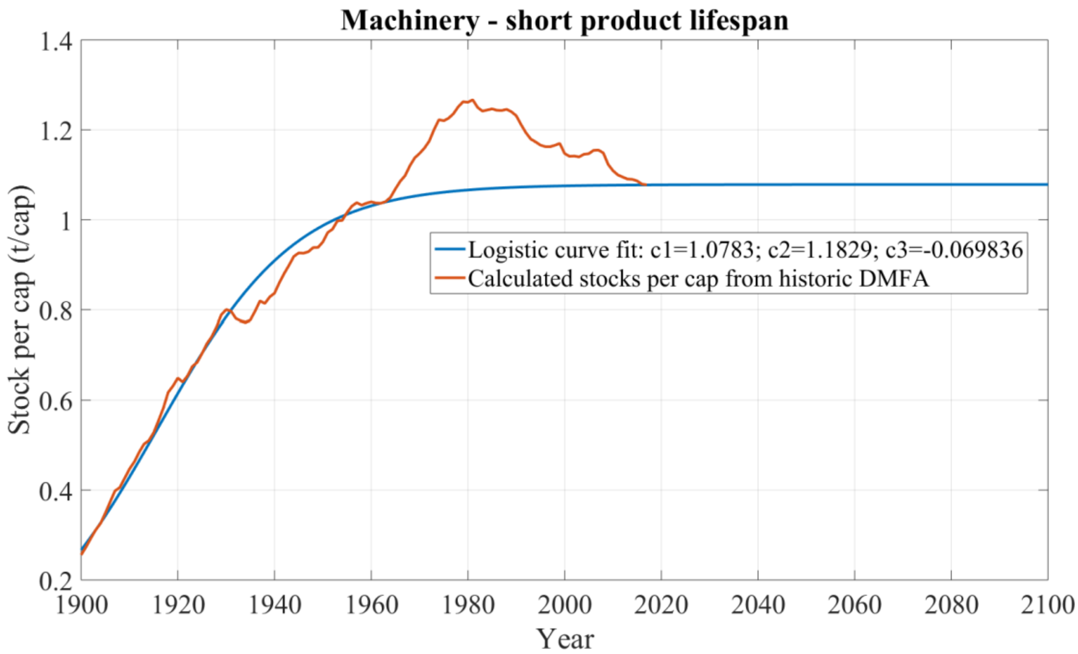

Figure S1-20: DMFA logistic curve fit to historical *spc* for the machinery sector

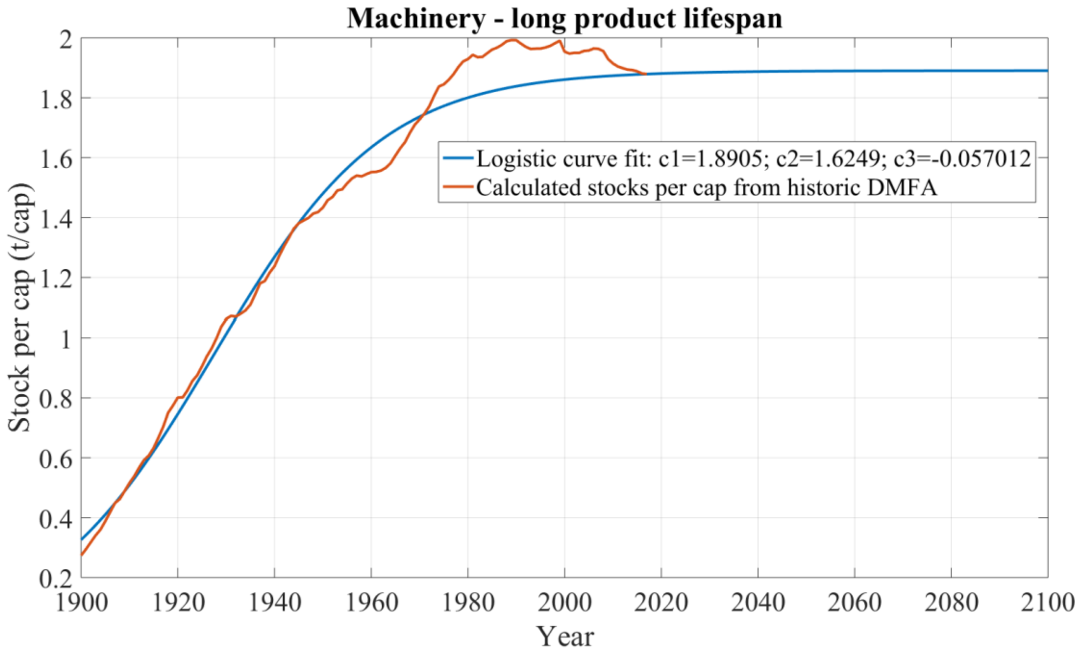

Figure S1-21: DMFA logistic curve fit to historical *spc* for the machinery sector

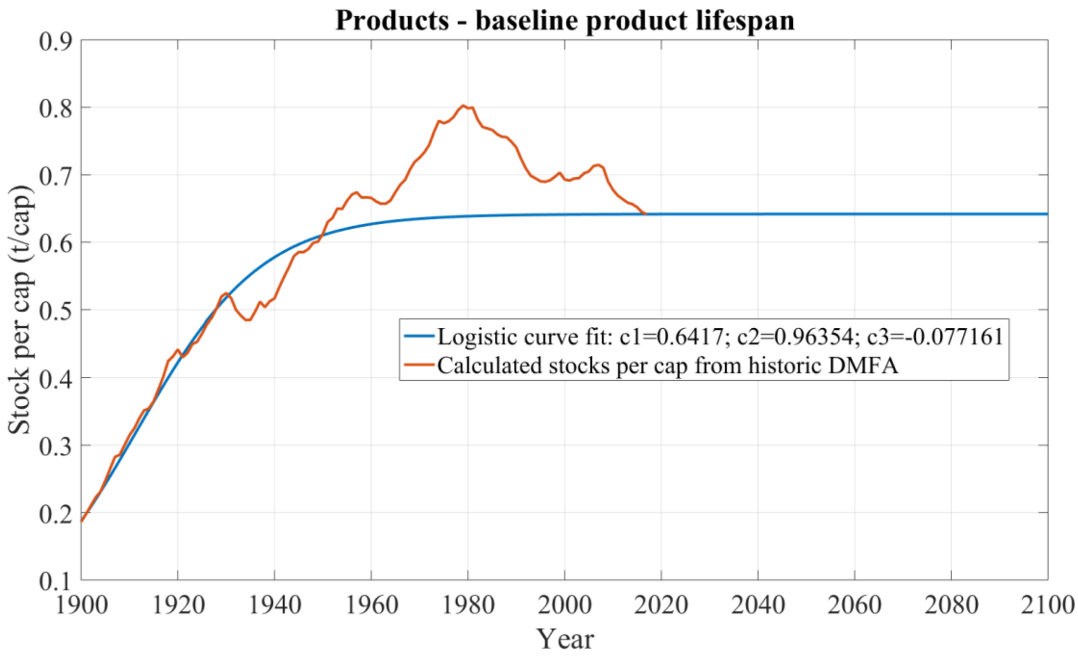

Figure S1-22: DMFA logistic curve fit to historical *spc* for the metal goods (products) sector

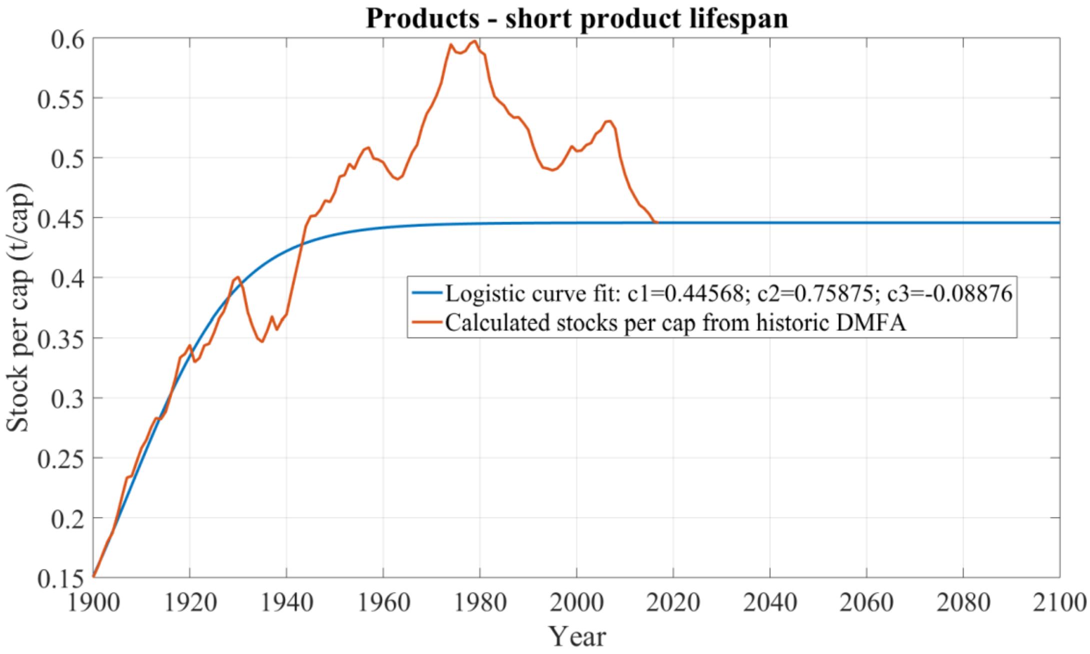

Figure S1-23: DMFA logistic curve fit to historical *spc* for the metal goods (products) sector

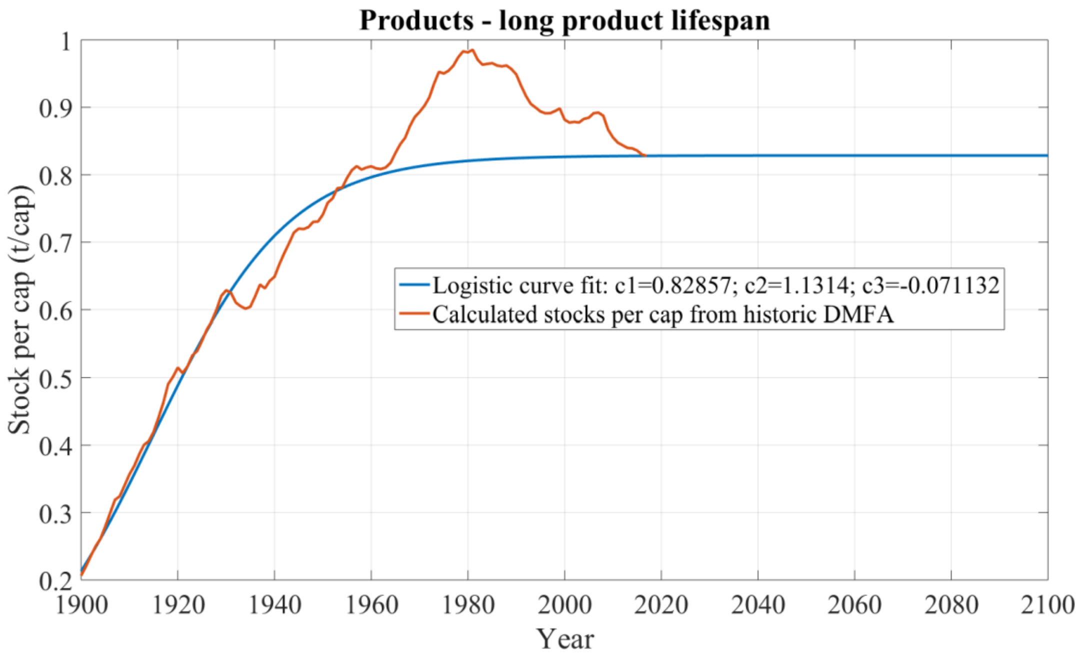

Figure S1-24: DMFA logistic curve fit to historical *spc* for the metal goods (products) sector

DMFA Results - Absolute stocks

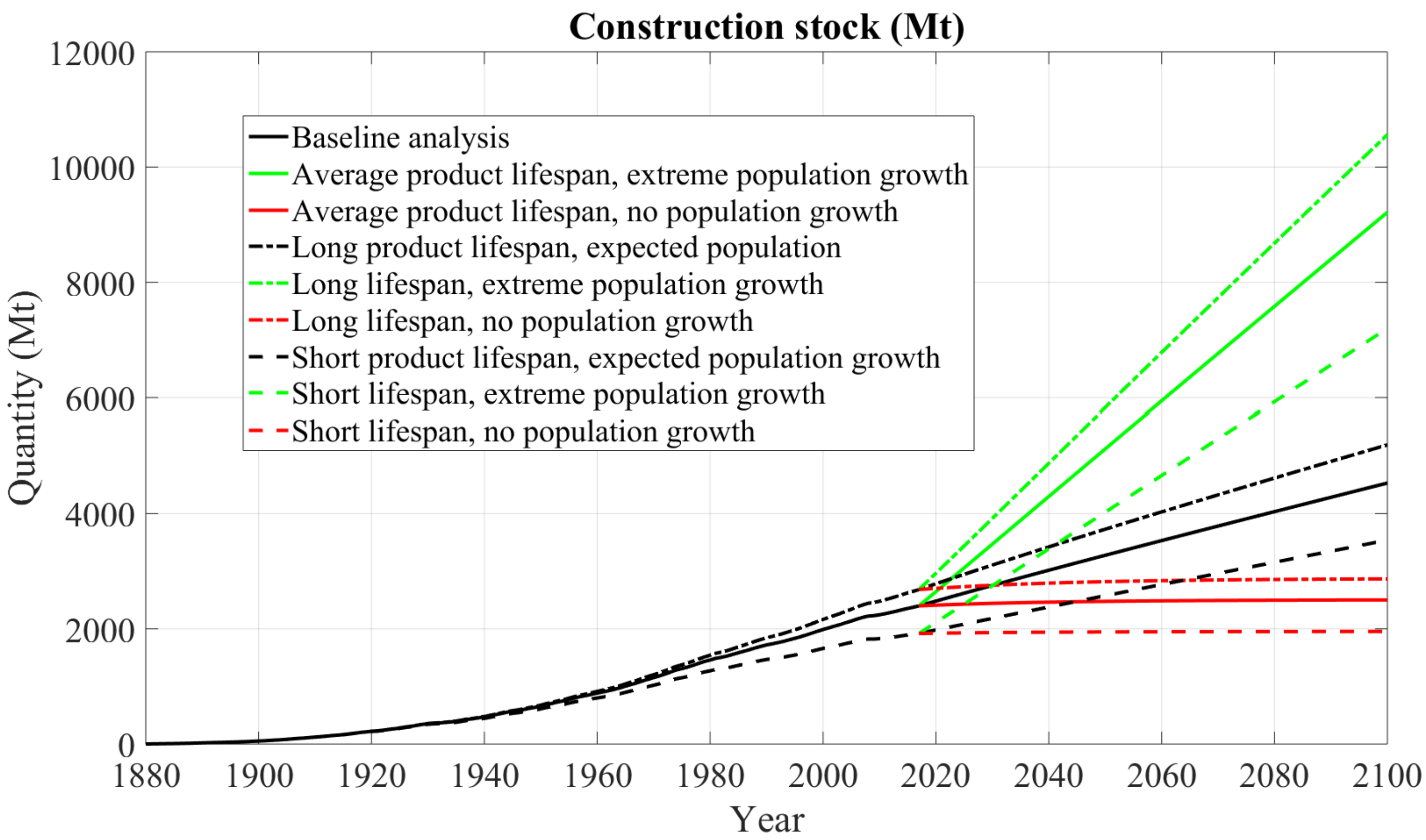

Figure S1-25: Absolute steel stocks in the construction sector

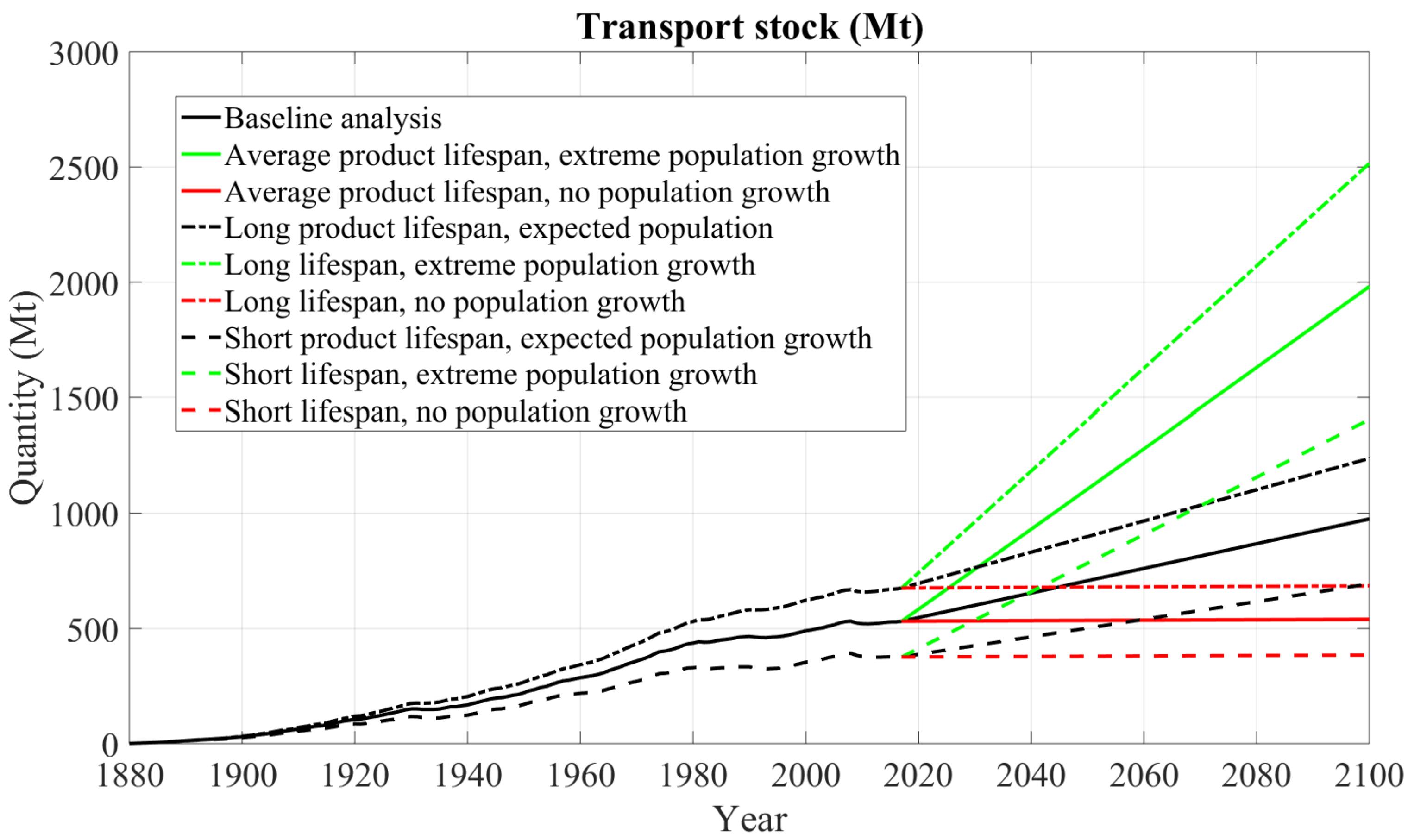

Figure S1-26: Absolute steel stocks in the transport sector

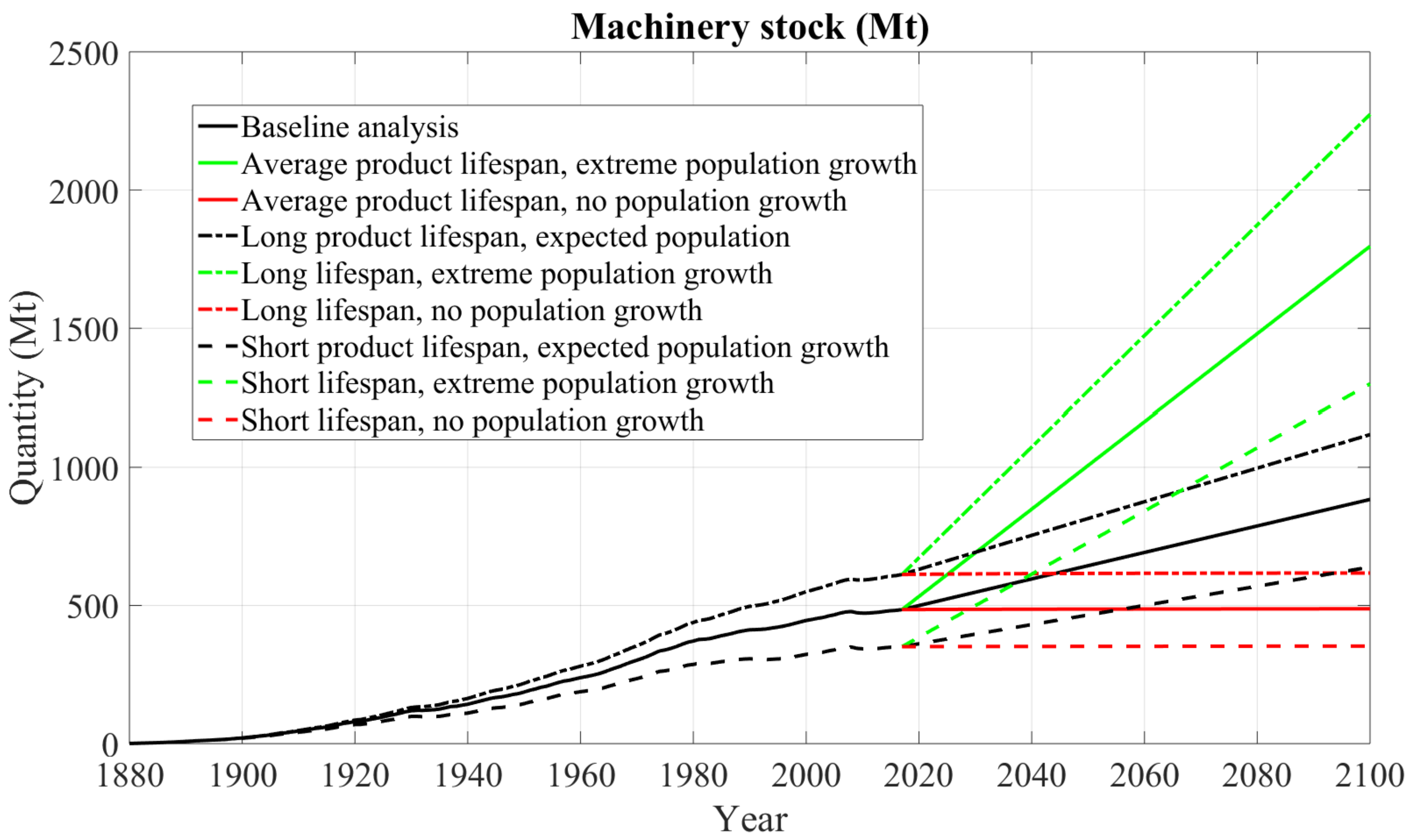

Figure S1-27: Absolute steel stocks in the machinery sector

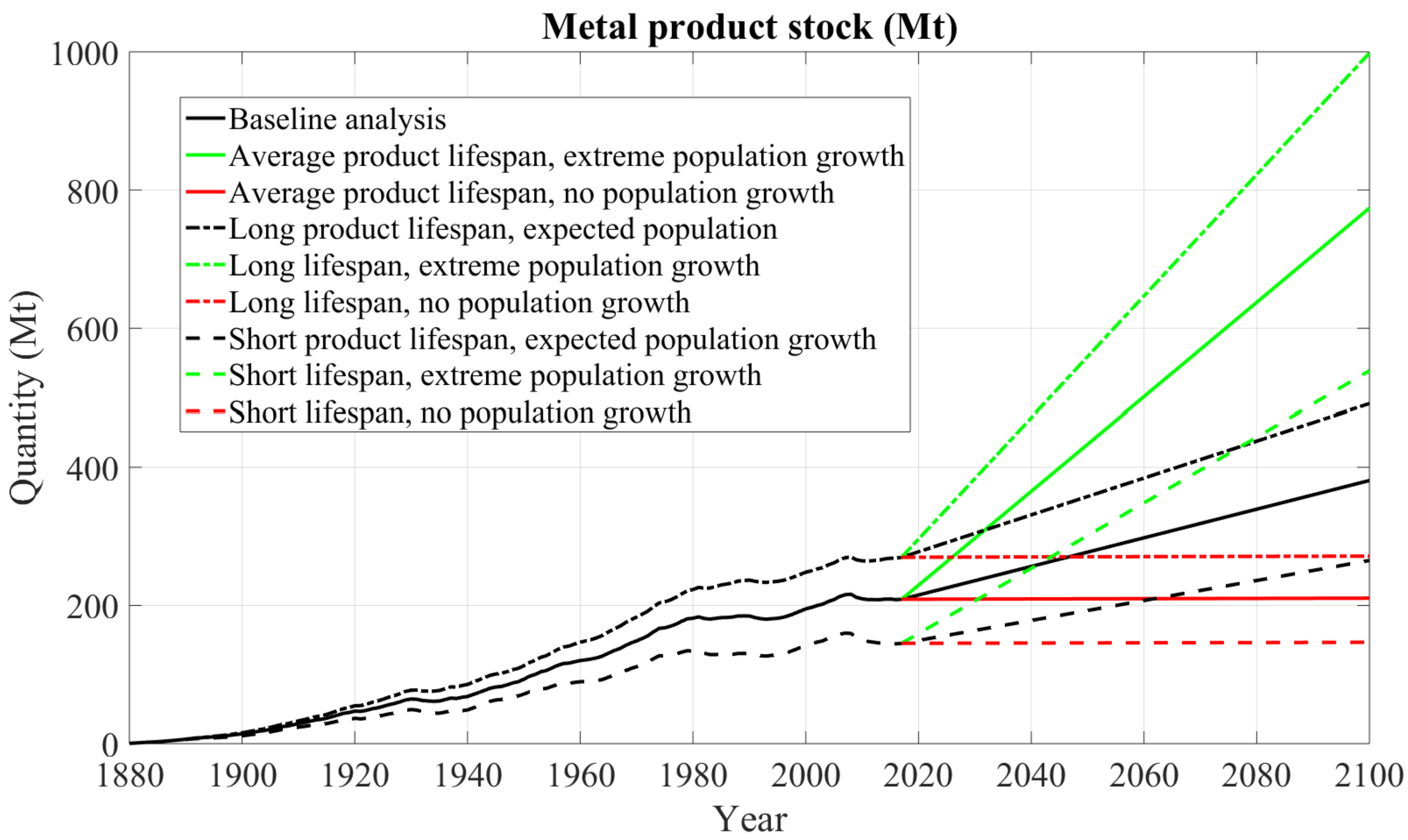

Figure S1-28: Absolute steel stocks in the metal goods (products) sector

Section S1-3: Intermediate steel embedded in end-use products

The U.S. quantity and fractional breakdown of intermediate steel products embedded in final goods is shown in Table S1-6.

Table S1-6: Annual U.S. manufacturing consumption of intermediate steel in 2014 (Zhu et al., 2019)

Intermediate products	**Breakdown (kt) of intermediate product destinations**				**Associated fractional breakdown (0-1)**			
	Construct-ion	**Transport**	**Machinery**	**Products**	**Construct-ion**	**Transport**	**Machinery**	**Products**
Casting	1384	2419	742	0	0.0329	0.1098	0.0321	0.0000
Tool steel	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Wire rods	1596	1171	617	0	0.0379	0.0532	0.0267	0.0000
Hot rolled bars	1190	2425	2220	0	0.0282	0.1101	0.0960	0.0000
Hot rolled coil	13474	3036	2703	63	0.3198	0.1378	0.1168	0.0095
Hot rolled narrow strip	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Cold rolled coil	0	3746	1191	4685	0.0000	0.1701	0.0515	0.7082
Cold rolled strip	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Plate	493	125	7066	0	0.0117	0.0057	0.3054	0.0000
Hot rolled galvanized coil	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Cold rolled galvanized	3572	7882	0	0	0.0848	0.3578	0.0000	0.0000
Cold rolled coil coated	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Cold rolled coil tinned	0	17	0	1868	0.0000	0.0008	0.0000	0.2823
Welded and seamless tube	3277	1162	8532	0	0.0778	0.0527	0.3687	0.0000
Rail	1087	0	66	0	0.0258	0.0000	0.0029	0.0000
Electrical sheet	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Light section	1474	44	0	0	0.0350	0.0020	0.0000	0.0000
Heavy section	5925	0	0	0	0.1406	0.0000	0.0000	0.0000
Construction (rail)	0	0	0	0	0.0000	0.0000	0.0000	0.0000
Rebar	8661	0	0	0	0.2056	0.0000	0.0000	0.0000
Totals	**42132**	**22027**	**23137**	**6616**	**1**	**1**	**1**	**1**

The U.S. quantity and fractional breakdown of intermediate steel products embedded in final goods is shown in Table S1-7.

Table S1-7: Annual global manufacturing consumption of intermediate steel in 2008 (Cullen et al., 2012)

Intermediate products	**Breakdown (Mt) of intermediate product destinations**				**Associated fractional breakdown (0-1)**			
	Vehicles	**Machinery**	**Construction**	**Goods**	**Vehicles**	**Machinery**	**Construction**	**Goods**
Light Sections			42		0.00	0.00	0.07	0.00
Heavy Sections			38		0.00	0.00	0.06	0.00
Rail		1	9		0.00	0.01	0.02	0.00
Rebar			165		0.00	0.00	0.28	0.00
Wire Rod	10	8	77	38	0.07	0.05	0.13	0.21
Hot Rolled Bar	15	36	4	29	0.11	0.20	0.01	0.16
Plate	27	30	6	25	0.19	0.17	0.01	0.14
HRC	6	30	88	6	0.04	0.17	0.15	0.03
HRC Galv.			9		0.00	0.00	0.02	0.00
HR Narrow Strip			18	15	0.00	0.00	0.03	0.08
CRC		19	60	29	0.00	0.11	0.10	0.16
CRC Galv.	58				0.41	0.00	0.00	0.00
CRC Coated				12	0.00	0.00	0.00	0.07
CRC Tinned				8	0.00	0.00	0.00	0.05
Electrical Sheet		8			0.00	0.05	0.00	0.00
Welded Tube	1	20	37	1	0.01	0.11	0.06	0.01
Seamless Tube	6	4	16		0.04	0.02	0.03	0.00
Tool steel	0	0	0	0	0.00	0.00	0.00	0.00
Cast Iron	17	15	27	9	0.12	0.09	0.05	0.05
Cast Steel		5		5	0.00	0.03	0.00	0.03
Totals	**140**	**176**	**596**	**177**	**1.00**	**1.00**	**1.00**	**1.00**

Section S1-4: Modeled copper concentration of DMFA steel scrap categories

The concentration of copper in the four different DMFA steel scrap sources is shown in Table S1-8. Three copper concentration scenarios (expected, low, and high) are modeled for each scrap source.

Table S1-8: DMFA scrap category copper concentrations used in this analysis

	Copper concentration (wt. %)		
Scrap Source	**Expected**	**Low**	**High**
Transport	0.3	0.2	0.5
Machinery	0.3	0.2	0.4
Construction	0.2	0.1	0.2
Goods	0.35	0.2	0.4

These copper contamination values were assigned according to values presented din Daehn et al.'s analysis and as calculated from 2017 U.S. collected scrap data, as summarized in Table S1-9.

Table S1-9: Previous scrap category copper concentration data

	Copper concentration (wt. %)			
Scrap Source	**Derived from collected U.S. scrap in 2017 (Table S1-17)**	**From Daehn et al.'s (2017) analysis**		
		Expected	**Low**	**High**
Transport	0.29	0.3	0.2	0.5
Machinery	0.34	0.25	0.2	0.4
Construction	0.33	0.1	0	0.1
Goods	0.30	0.4	0.2	0.3

Section S1-5: Imported metal in 2017 (and new product copper tolerances)

Direct imports of steel mill products (inc. copper tolerance)

Imports of steel mill products to the U.S. in 2017 were extracted from the U.S. Census Bureau (2018), which splits these imports into twenty sub-categories. The imported *billets, blooms and slabs* will be formed into intermediate products domestically; therefore, this category of imports is assigned to the various intermediate product import categories in the same ratio as domestically produced steel, as reported for steel mill products in Table 3 of the USGS 2014 iron and steel Minerals Yearbook (USGS, 2014a) and as reported for steel and iron castings in the mineral commodity summary report for (USGS, 2015).

In 2017, the U.S. imported 7.7 Mt of billet, bloom and slab (BBS). The breakdown into intermediate products is shown in Table S1-10.

Table S1-10: Breakdown of intermediate products formed in U.S. from imported Billets, Blooms. And Slabs

Intermediate product	**BBS (%)**	**Quantity (Mt)**
Hot Rolled Sheet and Strip	22.4%	1.73
Cold Rolled Sheet and Strip	11.6%	0.90
Hot Dip Galvanized sheet	15.2%	1.18
Electrogalvanized sheet	1.3%	0.10
Other metallic coated sheet	1.4%	0.11
Tinplate/Tin coat sheet	1.5%	0.12
Tin Free sheet/ BlackPlate	0.4%	0.03
Oil Country Goods	3.5%	0.27
Standard Pipe	0.8%	0.06
Other Pipe/Tube	0.8%	0.06
Plates, cut length	7.1%	0.55

Intermediate product	BBS (%)	Quantity (Mt)
Plates, in coils	3.2%	0.25
Reinforcing bar	7.6%	0.59
Wire Rod and Wire	2.7%	0.21
Hot Rolled Bar	5.2%	0.41
Cold Finished Bars	1.3%	0.10
Light Shaped bars	2.0%	0.16
Heavy sections	6.0%	0.47
Rail	1.0%	0.08
Steel Castings	0.4%	0.03
Iron Castings	4.3%	0.34
	Total	7.73

All directly imported metal was then grouped according to the intermediate product categories shown in Table S1-8. In total, the U.S. imported 34.5 Mt of steel mill products in 2017.

Table S1-11: Total U.S. direct imports of steel mill products in 2017 (and copper tolerances of new intermediate steel products used in this analysis)

Inter-mediate product	**Copper tolerance (wt. %)[2]**			**Imports in 2017 (Mt)**	**Breakdown of imports according to U.S. Census Bureau category**			
	Esti-mate	Max.	Min.					
Steel/iron for castings[1]	0.75[3]	0.75[3]	0.75[3]	0.41	*Ingots And Steel For Castings* 0.04	*BBS - steel castings* 0.03	*BBS - iron castings* 0.34	
Tool steel[2]	0.75[3]	0.75[3]	0.75[3]	0.16	*Tool steel* 0.16			
Wire rods	0.1	0.2	0.1	2.42	*Wire rod* 1.43	*Wire drawn* 0.78	*BBS - Wire Rod and Wire* 0.21	
Hot rolled bars	0.15	0.2	0.1	2.03	*Bars - hot rolled* 1.20	*Bars - cold finished* 0.32	*BBS - Cold Finished Bars* 0.10	*BBS - hot rolled bar* 0.41
Hot rolled coil	0.1375	0.2	0.06	3.52	*Sheets (hot rolled)* 1.93	*Allocation of BBS - Hot Rolled Sheet and Strip[4]* 1.58		
Hot rolled narrow strip	0.15	0.2	0.06	0.33	*Strip (hot rolled)* 0.18	*Allocation of BBS - Hot Rolled Sheet and Strip[4]* 0.15		

Inter-mediate product	Copper tolerance (wt. %)[2]			Imports in 2017 (Mt)	Breakdown of imports according to U.S. Census Bureau category				
	Esti-mate	Max.	Min.						
Cold rolled coil	0.1	0.2	0.06	3.49	*Sheets (cold rolled)* 2.66	*Allocation of BBS - Cold Rolled Sheet and Strip*[5] 0.83			
Cold rolled strip	0.1	0.2	0.06	0.28	*Strip (cold rolled)* 0.21	*Allocation of BBS - Cold Rolled Sheet and Strip*[5] 0.07			
Plate	0.15	0.2	0.1	2.89	*Plate in coils* 1.24	*Plates cut lengths* 0.75	*Steel piling* 0.10	*BBS - plates in coils* 0.25	*BBS - plates cut to lengths* 0.55
Hot rolled coil galvanized	0.2	0.2	0.06	2.79	*50% of total galvanized sheet and strip* 1.62	*BBS - Hot Dip Galvanized sheet* 1.18			
Cold rolled galvanized	0.06	0.1	0.06	1.72	*50% of total galvanized sheet and strip*	*BBS - electro-galvanizing*			

Inter-mediate product	Copper tolerance (wt. %)[2]			Imports in 2017 (Mt)	Breakdown of imports according to U.S. Census Bureau category												
	Esti-mate	Max.	Min.														
					1.62	0.10											
Cold rolled coil coated	0.06	0.06	0.04	1.17	*Sheets & Strip All Oth Met Coat*	*BBS - metal sheet coated*											
					1.06	0.11											
Cold rolled coil tinned	0.06	0.06	0.04	1.27	*Tin plate*	*Tin free steel*	*Black plate*	*BBS - tin plate*	*BBS - tin free*								
					0.85	0.21	0.06	0.12	0.03								
Welded & seamless tube	0.15	0.2	0.1	8.01	*Total Pipe & Tubing*	*Stainless pipe & tubing*	*Oil country goods*	*Line pipe*	*Standard pipe*	*Mech-anical tubing*	*Pressure tubing*	*Struct-ural pipe and tube*	*Pipe for piling*	*BBS - oil country goods*	*BBS - standard pipe*	*BBS - other pipe and tube*	
					0.02	0.14	3.10	1.2	1.06	0.61	0.06	0.57	0.04	0.27	0.06	0.06	
Rail	0.15	0.2	0.1	0.29	*Rail standard*	*BBS*											
					0.21	0.08											
Electrical sheet	0.06	0.15	0.06	0.10	*Sheets and strip - electrical*												
					0.10												
Light section	0.3	0.3	0.2	0.31	*Bars - Light Shaped*	*BBS*											

Inter-mediate product	Copper tolerance (wt. %)[2]			Imports in 2017 (Mt)	Breakdown of imports according to U.S. Census Bureau category	
	Esti-mate	Max.	Min.			
					0.15	0.16
Heavy section	0.3	0.3	0.2	1.25	*Structural Shapes Heavy* 0.78	*BBS* 0.47
Construct-ion - rail	0.3	0.3	0.2	0.02	*Rails all other* 0.02	*Railroad accessories* 0.01
Rebar	0.4	0.5	0.4	2.01	*Bars - reinforcing* 1.42	*BBS* 0.59
			Total	**34.47**		

Notes. 1: These intermediate product categories are not included in Daehn et al.'s (2017) analysis and instead come straight from the U.S. Census Bureau data (U.S. Census Bureau, 2018); 2: All copper tolerance values taken from Daehn et al. (2017) except where otherwise stated in these notes; 3: Copper tolerance data for castings and tool steel taken from (Alro, 2015); 4: Hot rolled sheet and strip (produced from BBS) assigned to "hot rolled coil" and "hot rolled narrow strip" in same proportions as imported "sheets (hot rolled)" and "strip (hot rolled)"; 5: Cold rolled sheet and strip (produced from BBS) assigned to "cold rolled coil" and "cold rolled strip" in same proportions as imported "sheets (cold rolled)" and "strip (cold rolled)"

Indirect imports of steel in finished goods (inc. copper tolerance)

Trade of 29 steel intensive product categories is analyzed (see Table S). The same 29 categories were used in Wang et al.'s (2007b) analysis of global iron cycles. Data on the indirect import and export of these goods is provided by the U.N. Comtrade Database (U.N., 2018). The Comtrade data shows the value of each category in 2017 U.S. dollars (USD). The quantity (in kilograms) of the import and export category is also reported for 15 of the categories. This sub-section describes how the Comtrade data was used to estimate the quantity of steel imported and exported in each of the 29 product categories.

A conversion factor from product mass to steel mass was applied to the Comtrade mass data using iron fractions presented on page S8 of the Supporting Information from Wang et al.'s (2007b) article. Wang et al. (2007b) provide steel content statistics for all 29 product categories used in this analysis. Subsequently the mass of imported steel can be readily calculated for the 15 categories in which product mass import data is available from Comtrade. An empirical equation describing the steel intensity of imports (kg.steel per USD of trade) is derived in order to predict the steel imported within the 14 other product categories.

A series of regression analyses are performed on the depedence of the steel intensity in the 15 known categories on a range of product attributes (product category, steel fraction by mass, level of fabrication, and complexity of the energy conversion systems in the product). The results of the regression analyses were compared primarily using the R squared and Adjusted R squared statistic.

The products were split into 4 low resolution product categories: transport, machinery, electrical equipment, and other. No dependence of steel intensity based on this produict categorization could be observed in the data. The dependence of steel intensity on the steel fraction by mass in the product is shown in Figure S1-29.

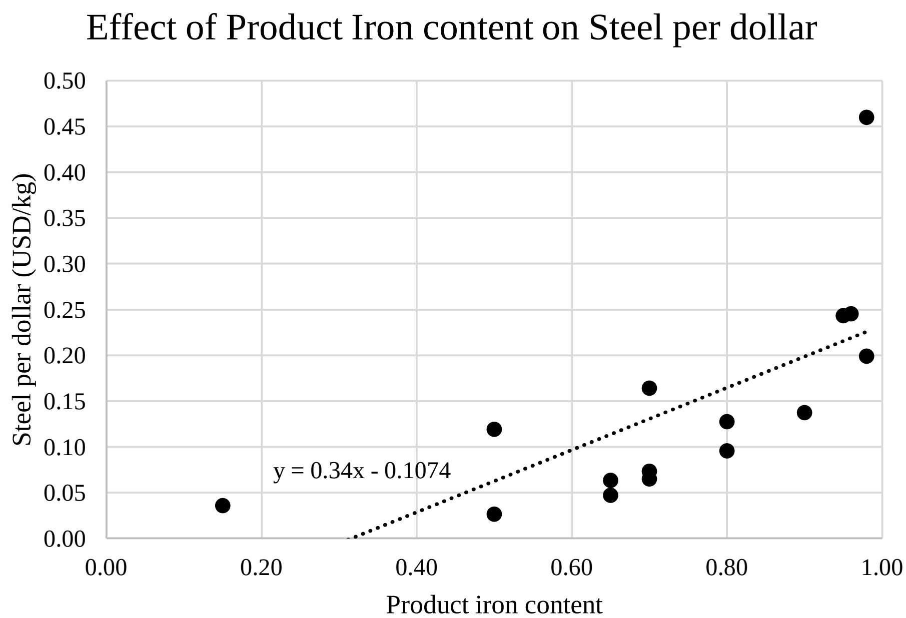

Figure S1-29: Effect of product steel fraction by mass on steel intensity

It was observed in the empirical data that products have a lower steel intensity if, during their production, there is a higher degree of fabrication and assembly (e.g. automobiles), or if the final product contains complex sub-assemblies that convert energy from one form to another (e.g. electrical motors or combustion engines). Hence, we characterize the products by introducing two new indices, both equal to values between 0 and 1: (a) the degree of fabrication and assembly (as shown in Table S1-12); and (b) the complexity of the present energy transformation system (as shown in Table S1-13). These characterizations inevitably contain a degree of subjectivity but the allocation of values is justified for all assigned products in Table S1-12 and Table S1-13.

Table S1-12: Degree of fabrication & assembly (high=1; low=0)

Fabrication & Assembly Index (0-1)	Justification	Products
0.00	Products that come straight out of metal forming equipment ready to be shipped to the customer	Nuts, bolts, screws, rivets, washers of iron/steel; Nails, tacks, staples, spikes, etc. of iron or steel
0.25	Products that require minimal, low skill labor to fabricate and/or assemble before shipping to the customer	Manufactures of metal; Casks, drums, etc.; Domestic Utensils of iron or steel; Perambulators, toys, games, and sporting goods; Tools for use in the hand or in machines
0.50	Products that require moderate, medium skill labor to fabricate and/or assemble before shipping to the customer	Metal furniture; Rubber tires and tubes for vehicles and aircraft; Office Machines; Telecommunications apparatus
0.75	Products that require fabrication of many components for a sub-assembly	Bodies and Parts motor vehicles excl. Motorcycles; Internal combustion engines, not for aircraft; Trailers and other vehicles not motorized and parts; Wire products excl. electric and fencing grills; Rail and tram cars, not mechanically propelled
1.00	Products that require extensive, potentially high skill labor, fabrication of hundreds of components	Passenger motor cars, other than buses; Lorries and trucks, including ambulances, etc.; Domestic Electrical Equipment; Agricultural machinery and implements; Road tractors for tractor trailer combinations; Machinery and appliances non electrical parts; Other electrical machinery and apparatus; Machines for special industries; Ships and boats; Electric power machinery and switchgear; Scientific, medical, and optical instruments; Metalworking machinery; Textile and leather machinery

Table S1-13: Presence of energy transformation system (no=0; yes=1)

Energy Conversion Index (0-1)	Justification	Products
0.00	Products that contain no energy transformation system	Manufactures of metal; Nuts, bolts, screws, rivets, washers of iron/steel; Trailers and other vehicles not motorized and parts; Metal furniture; Casks, drums, etc.; Rubber tires and tubes for vehicles and aircraft; Domestic Utensils of iron or steel; Nails, tacks, staples, spikes, etc. of iron or steel; Wire products excl. electric and fencing grills; Rail and tram cars, not mechanically propelled; Perambulators, toys, games, and sporting goods; Tools for use in the hand or in machines

0.50	Machines that contain low cost energy conversion systems	Machinery and appliances non electrical parts; Office Machines; Telecommunications apparatus
1.00	Machines that contain multiple energy conversion systems or whose main purpose is energy conversion	Passenger motor cars, other than buses; Bodies and Parts motor vehicles excl. Motorcycles; Lorries and trucks, including ambulances, etc.; Domestic Electrical Equipment; Internal combustion engines, not for aircraft; Agricultural machinery and implements; Road tractors for tractor trailer combinations; Other electrical machinery and apparatus; Machines for special industries; Ships and boats; Electric power machinery and switchgear; Scientific, medical, and optical instruments; Metalworking machinery; Textile and leather machinery

Figure S1-30 and Figure S1-31 show the dependence of the product steel intensity on the degree of fabrication/assembly and the complexity of the energy transformation system respectively.

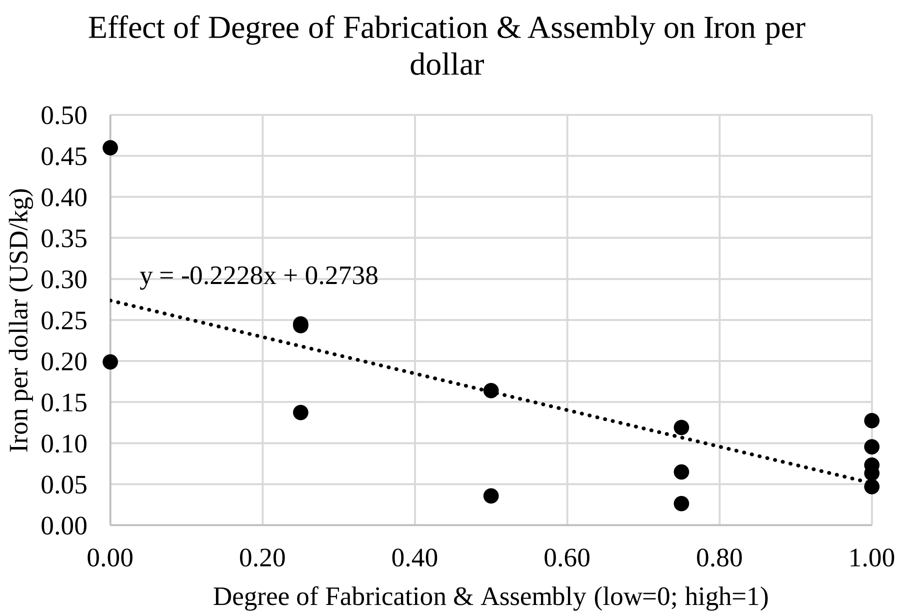

Figure S1-30: Effect of fabrication and assembly on steel intensity

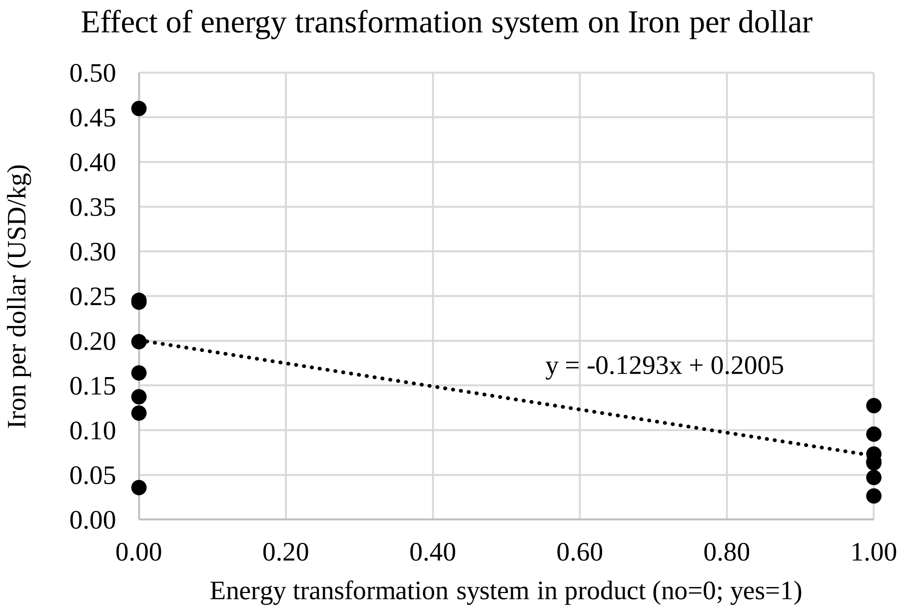

Figure S1-31: Effect of complexity of energy transformation system present on steel intensity

Four linear regressions are performed on the complete empirical data (15 known dependent variables). The results of the analyses are summarized in Table S1-14.

Table S1-14: Comparison between different linear regression models

Regression	**Regression 1:** One independent variable = Iron content	**Regression 2:** Three independent variables = Iron content; Fabrication; Energy Conversion	**Regression 3:** Four independent variables = Category; Iron content; Fabrication; Energy Conversion	**Regression 4:** One independent variables = Category
R Square	0.47	0.71	0.77	0.46
Adjusted R Square	0.43	0.63	0.47	0.22

As described by Montgomery (2009), the R square statistic is a measure of the amount of reduction in the variability of the dependent variable obtained by using the regressor variables in the model (Montgomery, 2009). However, a large value of

R does not necessarily imply that the regression model is a good one. Adding a variable to the model will always increase the R square value regardless of whether the additional variable is statistically significant or not. Thus, it is possible for models that have large R square values to yield poor predictions of new observations or estimates of the mean response. In general, the adjusted R square statistic however will not always increase as variables are added to the model. In fact, if unnecessary terms are added, the value of will often decrease. When the R square and adjusted R square statistics differ dramatically, there is a good chance that nonsignificant terms have been included in the model. For Regression 3, Table S1-14 shows that despite having the highest R square value (0.77), it has a much lower adjusted R square value of 0.47. Given that there was no clear dependence of steel intensity on product categorization into transport, machinery, electrical or other then it is likely that regression 3 has introduced unnecessary terms. Subsequently, in this analysis we choose the results of regression 2 to model the steel intensity of the remaining 14 product categories based upon the iron content by mass, the fabrication/assembly complexity, and the complexity of the energy conversion system.

The resulting predictive equation, using the coefficient values produced in regression analysis number 2, is shown in equation S1 and used to estimate the steel intensity of the products highlighted in yellow in Table S1-15.

$$Iron\ intensity\ \left(\frac{kg}{USD}\right) = 0.04 + (0.25 \times iron\ content\ as\ mass\%) - (0.09 \times fab.index) - (0.05 \times energy\ conversion\ index) \quad (S1)$$

The above methodology was repeated for product exports, giving the equation shown below (equation S2):

$$Iron\ intensity\ of\ exports\ \left(\frac{kg}{USD}\right) = -0.03 + (0.35 \times iron\ content\ as\ mass\%) - (0.065 \times fab.index) - (0.065 \times energy\ conversion\ index) \quad (S2)$$

Table S1-15: U.S. imports of 29 product categories in 2017. Data in yellow is calculated as part of this article's work

All 2017 imports												
All inferred values are shown highlighted in yellow					**Data from Commodity Trade (Comtrade) Database**							
No.	**SITC-1 Code**		**Parts or Final Product**	**%Fe**	**Value (units)**	**Value (USD)**	**Value (kg)**	**Iron value in 2017 (kg)**	**Mass per unit (kg/unit)**	**Mass per dollar (kg/USD)**	**Iron per unit (kg)**	**Iron per dollar (kgs/USD)**
1	S1	7321	Passenger motor cars, other than buses	0.65	7925506	178810765021	12948748892	**8416686780**	1634	0.07	1061.97469	**0.047**
2	S1	719	Machinery and appliances non electrical parts	0.75		137455737441	19584448360	**14688336270**				**0.107**
3	S1	7328	Bodies and Parts motor vehicles excl. Motorcycles	0.70		66635892926	6183632622	**4328542835**		0.09		**0.065**
4	S1	698	Manufactures of metal	0.90		22120238110	3376302441	**3038672197**		0.15		**0.137**
5	S1	729	Other electrical machinery and apparatus	0.55		114628676365	6440698450	**3542384147**				**0.031**
6	S1	718	Machines for special industries	0.75		18971857727	2036957969	**1527718477**				**0.081**
7	S1	7323	Lorries and trucks, including ambulances, etc.	0.80	1075498	27276125258	3259749770	**2607799816**	3031	0.12	2424.73702	**0.096**
8	S1	735	Ships and boats	0.90		2555835532	334366604	**300929944**				**0.118**
9	S1	722	Electric power machinery and switchgear	0.55		56866382742	3195179730	**1757348851**				**0.031**
10	S1	7250	Domestic Electrical Equipment	0.65		10851783884	1058257799	**687867569**		0.10		**0.063**
11	S1	69421	Nuts, bolts, screws, rivets, washers of iron/steel	0.98		5168791299	1049691823	**1028697987**		0.20		**0.199**
12	S1	7115	Internal combustion engines, not for aircraft	0.50		26378390589	1394883902	**697441951**		0.05		**0.026**
13	S1	693	Wire products excl. electric and fencing grills	0.90		1459065605	313741896	**282367707**				**0.194**
14	S1	7333	Trailers and other vehicles not motorized and parts	0.50		3591018656	855693396	**427846698**		0.24		**0.119**
15	S1	861	Scientific, medical, and optical instruments	0.55		50559714852	2840823844	**1562453114**				**0.031**
16	S3	8213	Metal furniture	0.70		6124738010	1435740098	**1005018069**		0.23		**0.164**
17	S1	7316	Rail and tram cars, not mechanically propelled	0.85		626756114	133551257	**113518568**				**0.181**
18	S1	69221	Casks, drums, etc.	0.96		581461513	148586964	**142643485**		0.26		**0.245**
19	S1	715	Metalworking machinery	0.65		5315448607	455610126	**296146582**				**0.056**
20	S1	714	Office Machines	0.22		184379633312	18098472830	**3981664023**				**0.022**
21	S1	724	Telecommunications apparatus	0.20		100522038702	8359756918	**1671951384**				**0.017**
22	S1	712	Agricultural machinery and implements	0.70		7108904984	744524557	**521167190**		0.10		**0.073**
23	S1	894	Perambulators, toys, games, and sporting goods	0.20		19440649311	6423543285	**1284708657**				**0.066**
24	S1	695	Tools for use in the hand or in machines	0.85		7783517973	2081920533	**1769632453**				**0.227**
25	S1	6291	Rubber tires and tubes for vehicles and aircraft	0.15		14648616617	3494969595	**524245439**		0.24		**0.036**
26	S1	717	Textile and leather machinery	0.65		4997278760	428338410	**278419966**				**0.056**
27	S1	7325	Road tractors for tractor trailer combinations	0.80	60874	5808137524	925589003	**740471202**	15205	0.16	12163.9978	**0.127**
28	S1	69721	Domestic Utensils of iron or steel	0.95		2930550633	750383543	**712864366**		0.26		**0.243**
29	S1	69411	Nails, tacks, staples, spikes, etc. of iron or steel	0.98		825610105	387457879	**379708721**		0.47		**0.460**
			Color key: Transport; Electrical equipment; Machinery; Other				**Total (kgs)**	**58317254449**				
							Total (Mt)	**58.3**				

Table S1-15 shows that indirect steel imports were 58 Mt in 2017. Data from the World Steel Association is not so recent (see Figure S1-32) but the trend is consistent with the data shown in Table S1-15.

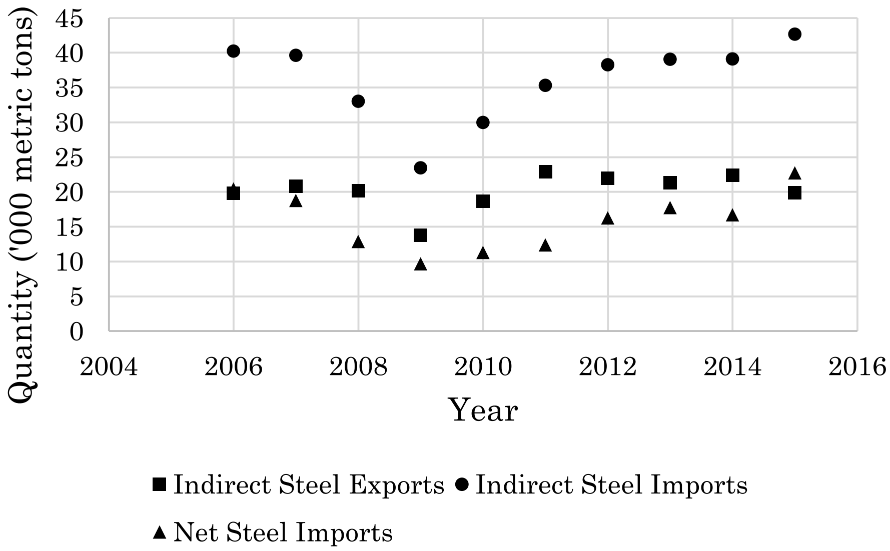

Figure S1-32: Indirect U.S. steel trade. Data from the Steel Statistical Yearbook report published by the World Steel Association (WSA, 2017)

Section S1-6: Scrap discards in 2017

U.S. steel scrap exports in 2017

In 2017, the U.S. exported 14 Mt of steel scrap (USGS, 2018b). At the time of writing, the types of steel scrap exported in 2017 were unavailable; therefore, the fractional breakdown of exported scrap categories was assumed equal to the latest year for which values were available, which was 2014, in which 15.1 Mt of EOL steel scrap (excluding manufacturing scrap) were exported. The exported scrap categories are listed in Table 11 of the 2014 Minerals Yearbook for Iron and Steel Scrap (USGS, 2014b). Table S1-13 presents the estimated quantity of exported scrap in 2017 and the copper contamination in each of the categories according to the concentrations from DJJ (2018), Leroy (1995) and Kostetsky et al. (2000).

Table S1-16: The copper content and quantity of U.S. exported EOL steel scrap quantities in 2017

Scrap industry category	Copper content (%)	Scrap quantity exported (Mt)			
		2014			Scaled 2017 value
		Total	Categories from USGS		
#1 HM	0.24	4.87	No. 1 heavy-melting scrap 4.87		**4.53**
#2 HM	0.46	0.88	No. 2 heavy-melting scrap 0.88		**0.81**
3' P&S	0.18	0.77	Cut plate and structural 0.765	Ships 0.01	**0.72**
Std. shredded	0.23	4.66	Shredded steel scrap 4.66		**4.33**
#2 Bdls.	0.45	0.02	No. 2 bundles 0.023		**0.02**
Tin plate	0.04	0.11	Tinned iron or steel 0.11		**0.11**
Rail crops	0.15	0.04	Used rails 0.04		**0.04**
Municipal scrap	0.45	2.32	Other steel scrap 2.32		**2.16**
Steel	0.15	0.00			**0.00**

Scrap industry category	Copper content (%)	Scrap quantity exported (Mt)		
		2014		Scaled 2017 value
		Total	Categories from USGS	
wheels				
Railcar sides	0.2	0.00		**0.00**
Steel cans	0.05	0.00		**0.00**
			Remelting scrap ingots	
All other carbon steel	0.28	0.02	0.02	**0.01**
			Other alloy steel scrap	
Alloy steel scrap	0.28	0.53	0.53	**0.49**
Other mixed scrap	0.45	0.00		**0.00**
			Iron scrap	
Cast iron scrap	0.28	0.30	0.30	**0.28**
			Stainless steel scrap	
Stainless steel scrap	1.5	0.55	0.55	**0.51**
	Total	**15.07**		**14.00**

U.S. steel scrap sent to landfill or hibernating scrap in 2017

Table S1-17 shows the calculation of U.S. scrap collection in 2014 (52.1 Mt, data from Table 2 in USGS, 2014) and the estimated quantity of U.S. scrap collected in 2017 based on scaling the 2014 values by the ratio of USGS recorded apparent consumption of scrap in the two years (58 Mt in 2014 and in 62 Mt 2017). The quantity of U.S. scrap sent to landfill or hibernating stocks in 2017 was estimated based on the weighted recycling rates for each scrap category (i.e., the sectoral breakdown of each scrap category (Table S1-17) and the recycling rate for each end-use sector (Table S1-18)). Apparent consumption of scrap in the U.S. in 2014 and 2017 was 58 Mt and 62 Mt respectively (USGS, 2018b).

<table>
<tr><th rowspan="2">Scrap industry category</th><th rowspan="2">Copper content</th><th rowspan="2">Sector</th><th colspan="4">2014</th><th colspan="5">2017</th></tr>
<tr><th>Total collected (Mt)</th><th>U.S. consumer receipts (Mt)</th><th>Export scrap (Mt)</th><th>Import scrap (Mt)</th><th>Total collected (Mt)</th><th colspan="3">Total quantity of available discards (Mt)</th><th>Total quantity of scrap sent to landfill (Mt)</th></tr>
<tr><td rowspan="2">#1 HM</td><td rowspan="2">0.24</td><td rowspan="2">Construction (70%), machinery (20%) & transport (10%)</td><td></td><td>No. 1 heavy-melting steel</td><td>No. 1 heavy-melting scrap</td><td>No. 1 heavy-melting scrap</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>9.23</td><td>4.67</td><td>4.87</td><td>0.311</td><td>9.87</td><td colspan="3">13.74</td><td>3.87</td></tr>
<tr><td rowspan="2">#2 HM</td><td rowspan="2">0.46</td><td rowspan="2">Construction (50%), machinery (25%), transport (25%)</td><td></td><td>No. 2 heavy-melting steel</td><td>No. 2 heavy-melting scrap</td><td>no. 2 heavy-melting scrap</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>6.21</td><td>5.58</td><td>0.877</td><td>0.243</td><td>6.64</td><td colspan="3">9.31</td><td>2.67</td></tr>
<tr><td rowspan="2">3' P&S</td><td rowspan="2">0.18</td><td rowspan="2">Construction (33%), transport (33%), & machinery (33%)</td><td></td><td>Cut structural & plate</td><td>Cut plate and structural</td><td>Ships</td><td>Cut structural & plate</td><td>Ships</td><td></td><td></td><td></td></tr>
<tr><td>5.19</td><td>4.67</td><td>0.77</td><td>0.01</td><td>0.25</td><td>0.003</td><td>5.55</td><td>7.95</td><td>2.41</td></tr>
<tr><td rowspan="2">Std. shredded</td><td rowspan="2">0.23</td><td rowspan="2">Transport (62.5%) & products (37.5%)</td><td></td><td>Shredded or fragmentized</td><td>Shredded steel scrap</td><td>Shredded steel scrap</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>19.28</td><td>15.20</td><td>4.66</td><td>0.582</td><td>20.61</td><td colspan="3">26.57</td><td>5.96</td></tr>
</table>

Scrap industry category	Copper content	Sector	2014 Total collected (Mt)	2014 U.S. consumer receipts (Mt)	2014 Export scrap (Mt)		2014 Import scrap (Mt)	2017 Total collected (Mt)	2017 Total quantity of available discards (Mt)	2017 Total quantity of scrap sent to landfill (Mt)
#2 Bdls.	0.45	Machinery (20%), construction (26%), transport (35%), products (19%)		No. 2 and all other bundles	Electric furnace, 1' & under	No. 2 bundles	No. 2 bundles			
			1.05	0.95	0.11	0.023	0.037	1.12	1.56	**0.44**
Tin plate	0.04	Products (containers)				Tinned iron or steel	Tinned iron or steel			
			0.04			0.114	0.079	0.04	0.05	**0.02**
Rail crops	0.15	Construction		Railroad rails	Used rails		Used rails			
			0.21	0.25	0.041		0.073	0.23	0.30	**0.07**
Municipal scrap	0.45	Products (mix of containers and appliances)				Other steel scrap	Other steel scrap			
			1.70			2.32	0.623	1.81	2.61	**0.80**
Steel	0.15	Transport								

Scrap industry category	Copper content	Sector	2014 Total collected (Mt)	2014 U.S. consumer receipts (Mt)	2014 Export scrap (Mt)	2014 Import scrap (Mt)	2017 Total collected (Mt)	2017 Total quantity of available discards (Mt)	2017 Total quantity of scrap sent to landfill (Mt)
wheels			0.00					0.00 0.00	**0.00**
Railcar sides	0.2	Transport							
			0.00					0.00 0.00	**0.00**
Steel cans	0.05	Products (containers)		Steel cans, postconsumer					
			0.10	0.10				0.10 0.15	**0.05**
All other carbon steel	0.28	Machinery (25%), construction (32%), transport (43%)		All other carbon steel scrap	Remelting scrap ingots	Remelting scrap ingots			
			2.58	2.57	0.015	0.003	2.76	3.81	**1.05**
Alloy steel scrap	0.28	Machinery (25%), construction (32%), transport (43%)		Alloy steel (except stainless)	Other alloy steel scrap	Other alloy steel scrap			
			0.51	0.51	0.527	0.529	0.54	0.75	**0.21**
Other mixed scrap	0.45	Machinery (25%), constructi		Other mixed scrap	Slag scrap Ingot mold				

Scrap industry category	**Copper content**	**Sector**	**2014 Total collected (Mt)**	**2014 U.S. consumer receipts (Mt)**	**2014 Export scrap (Mt)**			**2014 Import scrap (Mt)**	**2017 Total collected (Mt)**	**2017 Total quantity of available discards (Mt)**		**2017 Total quantity of scrap sent to landfill (Mt)**
		on (32%), transport (43%)				& stool scrap						
			3.00	2.30	0.68	0.024				3.21	4.43	**1.23**
Cast iron scrap	0.28	Transport (44%) & Machinery (56%)		Machinery and cupola cast iron	Motor blocks	Other iron scrap	Iron scrap	Iron scrap				
			1.77	0.39	0.20	1.11	0.3	0.23	1.89	2.91		**1.01**
Stainless scrap	1.5	Machinery (20%), construction (26%), transport (35%), products (19%)		Stainless	Stainless			Stainless				
			1.23	1.013	0.548			0.329	1.32	1.83		**0.52**

<table>
<tr><th rowspan="2">Scrap industry category</th><th rowspan="2">Copper content</th><th rowspan="2">Sector</th><th colspan="7">2014</th><th colspan="6">2017</th></tr>
<tr><th>Total collected (Mt)</th><th>U.S. consumer receipts (Mt)</th><th colspan="3">Export scrap (Mt)</th><th colspan="2">Import scrap (Mt)</th><th>Total collected (Mt)</th><th colspan="4">Total quantity of available discards (Mt)</th><th>Total quantity of scrap sent to landfill (Mt)</th></tr>
<tr><td colspan="3">Total</td><td>52.09</td><td colspan="2">Consumer receipts:</td><td>40.31</td><td colspan="2">Export:</td><td>15.07</td><td>Import:</td><td>3.293</td><td>55.68</td><td>75.97</td><td colspan="2">20.29</td></tr>
</table>

Table S1-17: USGS scrap collection data for 2014 (consumer receipts, export scrap, and import scrap) and estimated quantity of scrap sent to landfill (including hibernating stocks) in 2017

Table S1-18: Calculated U.S. scrap arising, collection and recycling rates for 2014

Scrap category	Scrap arising (DMFA, see S2)	Scrap collected (Table S1-17)	Implied recycling rate
Total	71.07 Mt	52.09 Mt	0.73
Construction	18.33 Mt	14.05 Mt	0.77
Transport	24.52 Mt	20.45 Mt	0.83
Machinery	14.56 Mt	8.1 Mt	0.56
Product	13.67 Mt	9.49 Mt	0.69

Table S1-19: Calculated U.S. LHSE scrap for 2017

		Quantity (Mt)		
Scrap industry category	**Copper content**	**Total Landfill & Export**	**Landfill & Hibernating stocks**	**Export**
#1 HM	0.24	**8.40**	3.9	4.5
#2 HM	0.46	**3.48**	2.7	0.8
3' P&S	0.18	**3.12**	2.4	0.7
Std. shredded	0.23	**10.29**	6.0	4.3
#2 Bdls.	0.45	**0.46**	0.4	0.0
Tin plate	0.04	**0.12**	0.0	0.1
Rail crops	0.15	**0.11**	0.1	0.0
Municipal scrap	0.45	**2.95**	0.8	2.2
Steel wheels	0.15	**0.00**	0.0	0.0
Railcar sides	0.2	**0.00**	0.0	0.0
Steel cans	0.05	**0.05**	0.0	0.0
All other carbon steel	0.28	**1.07**	1.1	0.0
Alloy steel scrap	0.28	**0.70**	0.2	0.5
Other mixed scrap	0.45	**1.23**	1.2	0.0
Cast iron scrap	0.28	**1.29**	1.0	0.3
Stainless steel scrap	1.5	**1.03**	0.5	0.5
	Total	**34.29**	**20.3**	**14.0**

Section S1-7: U.S. steel mass & money trade flows

Table S1-20: Data used to construct Figure 6 in the main manuscript

		Imports		Exports		Net	
		Mass (Mt)	**Value ($ billion)**	**Mass (Mt)**	**Value ($ billion)**	**Mass (Mt)**	**Surplus ($ billion)**
Raw materials	Iron ore*	3.5	0.26	12	0.9	8.5	0.6
	Pig iron	5.1	1.8	0.04	0.01	-5.1	-1.8
	DRI	3.3	0.97	1.16	0.53	-2.11	-0.4
Steel mill products		36	29.1	11	9.1	-25.0	-20.1
Finished goods**		58.3	1084	36	574	-22.3	-510.3
Scrap		3	1.5	14	4.9	11	3.4
Total		**109**	**1118**	**74**	**590**	**-35**	**-529**

*Includes mass of gangue
**Only the mass of iron and/or steel in the finished good is included in this calculation. The value, however, is the value of the whole product

The data presented in Table S1-20 comes from:

- USGS iron ore Mineral Commodity Summaries for 2018: https://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/mcs-2018-feore.pdf
- MIDREX 2017 world DRI production statistics: https://www.midrex.com/assets/user/news/MidrexStatsBook2017.5_.24_.18_.pdf
- Trade in Steel mill products from the USGS iron and steel mineral commodity summary (USGS, 2018a); the commodity report U.S. Census Bureau "Exhibit 2. U.S. Imports For Consumption of Steel Products" (U.S. Census Bureau, 2018); and the U.S. Department of Commerce Steel Export Report: https://www.trade.gov/steel/countries/pdfs/exports-us.pdf
- Indirect trade value calculated using United Nations Comtrade data as described in section S1-5.
- USGS iron and steel scrap Mineral Industry Survey in December 2017 (also contains pig iron data):

https://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap
/mis-201712-fescr.pdf

Section S1-8: Deriving low resolution map of U.S. 2017 steel flow

From the DMFA

- Aggregated consumption in 2017 is equal to 104 Mt.
- Aggregated end-of-life scrap arising in 2017 is equal to 74 Mt.

Table S1-21: DMFA results used to help produce the low resolution 2017 steel map (Figure 6 in the main article)

Sector	**spc (t/capita)**
Construction	7.36
Transport	1.63
Machinery	1.50
Metal goods (products)	0.64
Total	11.1

Other data sources used

Table S1-22: Data sources for producing the low resolution 2017 steel map (Figure 6 in the main article)

Data	**Value**	**Source**
Collected scrap	56 Mt	Table S
Scrap import	3 Mt	Dec 2017 Iron and Steel scrap industry survey results
Scrap export	14 Mt	Dec 2017 Iron and Steel scrap industry survey results
Landfill & hibernating stocks	74 Mt – 56 Mt = 18 Mt	Mass balance
Raw steel	82 Mt	USGS 2018 Iron and Steel Mineral Commodity Summary
BOF	32% = 26 Mt	USGS 2018 Iron and Steel Mineral Commodity Summary
EAF	68% = 56 Mt	USGS 2018 Iron and Steel Mineral Commodity Summary
Imports of semi-finished steel	8.4 Mt	USGS 2018 Iron and Steel Mineral Commodity Summary
Direct Imports of Steel mill products (including semi-	36 Mt (including ingots, blooms, billets, slabs)	USGS 2018 Iron and Steel Mineral Commodity

Data	Value	Source
finished products)		Summary
Exports of Steel mill products (including semi-finished products)	11 Mt	USGS 2018 Iron and Steel Mineral Commodity Summary
Indirect imports	58 Mt	Calculated using UN Comtrade data and equations S1 & S2
Indirect exports	36 Mt	Calculated using UN Comtrade data and equations S1 & S2
Forming scrap	10 Mt	Estimated from Syndergaard et al. (2019)
Fabrication scrap	26 Mt	Estimated from Syndergaard et al. (2019) & mas balance

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